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CONTENTS

3

Contributors

6

Dean's Foreword

7

Modelling And Static Stress Analysis of Shipyard Jib Crane With Finite Element Method

B. Ünal, I. Gerdemeli, C.E. Imrak

12

Generation Simulation of Helical Gear Drives by Rack Cutters With Asymmetric Teeth

M. C. Fetvacı, C. E. Imrak

16

The Effects of The Shaft Surface Roughness On Performance of The Rotary Shaft Seals

Y. Kerküklü, Z. Parlar, V. Temiz, C. E. Imrak

21

Design For Assembly And Maintainability In Computer Aided Engineering And a Case Study: Packaging

A. Ozdemirkiran, C. E. Imrak, M. C. Fetvacı

26

Measuring of Creep of Cement Paste With Optoelectronic Probe

P. Padevët

30

Metallographical Analysis of Compact Discs

P. Jonšta, P. Váňová, J. Malcharcziková

33

Structure And Mechanical Properties of Cr – Mo – V Cast Steels After Regenerative Heat Treatment

G. Golański, J. Kupczyk

38

Gunshot Wounds – Contribution To The Biomechanical Analysis

S. Mehremic, I. Karabegovic

43

Special Problems In The Analysis of Contact of Real Bodies

J. Menčík, L. Beneš

48

Vertical Differential Component of The Temperature Load Evaluated From The Long-Term Experiment Carried Out On The Prestressed Concrete Bridge

M. Polák, T. Plachý

53

Optimal Diagnostic Model of Rotating Machines

R. Antunovic

58

Statistical Verification of Zero Shrinkage In Sinters Based On Hydroxyapatite With Addition of Zirconium Phase

A. Dudek, C. Kolan

62

Simple Tools For Analysis And Experiments In Material Research

J. Menčík

67

Experimental Results Using Dilatometer For Hypereutectical Al-Si Alloys's Behaviors

B. Varga, I. Száva

72

Testing Device For Elastic Components of Coupling Systems

M. Procop, E. Chişu, I. Száva, P. Dani, B. Gálfi, J. Gergely, L. Lukács, B. Székely

76

Fractures of Rolls In Cold Rolling Mills

K. Titz, K. Konečná, M. Špok, M. Tvrđý

79

Use of Accoustic Emission During Testing of Pressurized Bottles

J. Crha, K. Titz, L. Vavrečka, M. Tvrđý

83

X-Ray Diffraction Studies On The Crystalline Morphology In The Composites Polypropylene With Glass Fibre

R. Caban, Z. Nitkiewicz

87

Crystallization Ability of Aluminosilicate (Diabase) Glasses For The Production of Fibrous Insulating Materials

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The long-term cooperation between Polish and Slovak researchers in the field of machine design and materials engineering resulted in nine meetings held in Poland and Slovakia since 1996 under the common name "Theoretical and Experimental Problems of Materials Engineering". Czech researchers have been involved in organization of these conferences since 2003 and have been honoured by organization of the jubilee 10th meeting in Rožnov, 2005 (PiME05). Last conference was located in the beautiful spa region of the town Rajecké Teplice in Slovakia. The conference was organized by the Faculty of Industrial Technologies in Púchov, University of Alexander Dubček in Trenčín in the period August 25th - 28th 2008.

The purpose of the conference is to present current results in materials engineering, chemistry and mechanics of materials, mechanics and design in applications.

The conference topics :

- A. Physical and chemical properties of materials, nanomaterials
- B. Mechanical properties of materials
- C. Experimental methods in materials engineering
- D. Mechanics and computer simulation

Second part of proceedings is devoted to the chemistry of materials.

MODELLING AND STATIC STRESS ANALYSIS OF SHIPYARD JIB CRANE WITH FINITE ELEMENT METHOD

B. Ünal, I. Gerdemeli, C. E. Imrak

Abstract

In this study, shipyard jib crane which is one of the lifting equipments frequently used in materials handling is investigated. Shipyard jib cranes which are affected by a number of load combinations can be used in seaports, shipyards and warehouses with a wide range of usage areas during the operation. Most important loads are self weight of the system elements and the movement of operation load. Moreover, it is considered that, additional forces act on the shipyard jib crane, particularly operating in open-air, arise from wind and climate conditions, the great stress values can be observed on shipyard jib crane, especially on its body. It is completely modeled utilizing computer aided design program named AutoCAD in 3-D solid modeling environment and also JIB crane's boom part is generated by using Hypermesh. Then linear static analyses of the finite element model of shipyard jib crane are computed by ABAQUS 6.7.1 solver under certain load combinations and boundary conditions.

Key words

shipyard jib crane, finite element method, stress analyses, solid modelling

Cranes are a combination of separate hoisting mechanisms with a frame for lifting or both for lifting and moving loads which can be freely suspended on or secured to them. Cranes are the best way of providing a heavy lifting facility covering virtually the whole area of the building. Jib crane affected by a number of load combinations can be used in seaports, shipyards and warehouses with a wide range of usage areas during the operation [1]. Their design features vary widely according to their major operational specifications such as: the type of motion of crane structure, weight and type of

the load, location of the crane, geometric features and environmental conditions. Since the crane design procedure is highly standardized with these components, main effort and time spent mostly for interpretation and implementation of available design standards. Considerable research studies have been carried out about structural and component stresses, safety under static loading and dynamic behaviour of cranes [2, 3, 4].

FEA systems now have powerful graphics capabilities, automated functionality, and advanced user interfaces that make the technol-

Type	Jib Crane
Max. Height of Hoisting	71.000 mm
Max. Height of Crane	(12.5m Radius) 75.120 mm
Span	10.000 mm
Hoisting Capacity	(12.5m – 20m Radius) 20ton
Hoisting Capacity	(50m Radius) 5 ton

Tab. 1: Specification of Jib Crane

ogy considerably faster and easier to use. These improvements notwithstanding, however, full-blown advanced FEA still requires considerable time and the expertise of a dedicated analyst with the knowledge necessary to apply proper mesh densities, element types, and boundary conditions.

In this study, calculations are done by using the rules of F.E.M (European Federation of Materials Handling) and DIN standards, which is used for shipyard jib crane. The system behavior is considered to be linear elastic and one of a finite element modeling software Hypermesh and ABAQUS were utilized for this study. The stress calculations of portal crane are examined with an illustrative example.

SPECIFICATION OF JIB CRANE

Shipyards jib crane consists of an inclined member (jib) capable of suspending a load at its outer end, or the jib being supported by a rope or other member attached to a vertical mast or frame. The outreach of the jib can be constant or variable, and the crane as a whole may be either fixed or movable. These are usually of the self propelled balanced level-luffing type with full-circle slewing [5].

JCs are used in machine shops for the circular movements of the loads around the machines. For example, in automobile industries JCs are used to load the crank cases for grinding main and cam bores and to unload them upon completion of the operation. As a complex system, JC has two major sub assemblies|a mechanical and an electrical. The mechanical subassembly consists of a column, an arm, bearings, housing for motor and gear box, gears, brake unit (pad-

dles and springs), chain, and a pulley. One end of the column rests on the bearings located in the arm while the other end is free. The rating of the arm is the maximum load that can be lifted using the JC. This value depends upon the deflection of the arm [6]. The most recognizable part of Jib crane is the boom. This is the steel arm of the crane that holds the load. Rising up from just behind the operator's cab. The boom is the essential piece of crane, allowing the machine to raise loads to heights of metres. Boom is assembled to revolving platform with joint of boom. Because of the length of boom and not effect by wind impression, it is designed with a cage construction. General construction specifications of the shipyard crane are listed in Tab. 1 [7].

The design values used in the crane from F.E.M Standards. Classification Load: Class of Utilization: U3, Load Spectrum Class: Q3, Appliance Groups: A4, Material: St-42. Classification of Mechanism: Hoisting Group: M5, Slewing Group: M5, Traverse Group: M5, Travel Group: M5. Diagram of load of shipyard crane is illustrated in Fig. 1.

ANALYSES OF JIB CRANE

A 20-ton-capacity shipyard jib crane of overall radius 20 m is selected as a study object and its configuration is shown in Tab. 1. The value of the dynamic coefficient is applied to the loading arising from the working load. The value of the amplifying coefficient depends upon the group classification of the application in this work. The jib and its attachments have to be designed to withstand the sum of the forces arising under service conditions. Amongst the forces to be included are those due to [7,8]

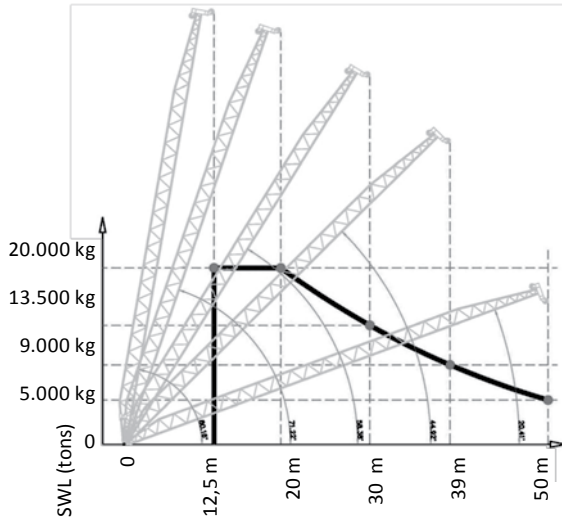


Fig. 1: Diagram of Load

- The load on the hook
- The weight of the jib and its attachments
- Acceleration (retardation) in slewing the load and jib
- Wind pressure acting on the load and jib
- The transvers shear of 2.5 percent of the maximum load

First maximum stresses and then shear stress are calculated using the F.E.M. rules (European Federation of Materials Handling). Using the finite element method for the considered crane boom values of stress are obtained. The static loads due to the dead weight, the loads due to the working load multiplied by the dynamic coefficient, and the two most unfavourable horizontal effects excluding buffer forces. Maximum stress consists of stress on boom dead weights (10.8 tons), stress from handling load (20 tons) and stress from vento rope load (25.5 tons) as illustrated in Fig. 2 [3,7].

Mechanical properties of the crane were gathered from a Turkish company named TRANSPORT TESISLERI Inc. This model can be used for the static analysis. The geometric characteristics of the crane and the crane's various elements are modeled and determined on the basis of the planned geometric layout. The support ends of the crane are assumed to be simple supported. They are generally located as

contact face of wheels. The solid model of jib crane structure was designed in AutoCAD and exported to SolidWorks to save as a IGES formatted file which will be read directly in Hypermesh software to generate the nodes as shown in Fig. 3.

The computer program, which runs on a WindowsXP operating system, is used to obtain the numerical solution for the stress analysis of the proposed crane structure. To model the boom part of Jib Crane with two-node linear (beam) element, Hypermesh and ABAQUS software was used to finite element analysis using the cage model generated as shown in Fig. 4.

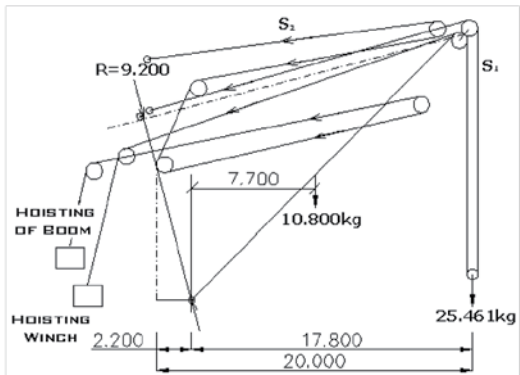


Fig. 2: Diagram of Force

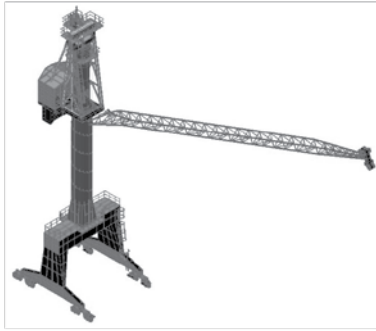
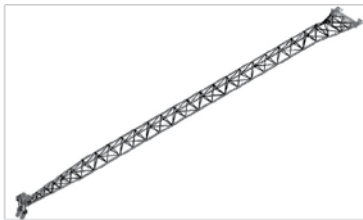


Fig. 3: Modelling of Jib Crane



(a) 3D model of the boom



(b) nodes on the model

Fig. 4: Modelling of the crane boom

It is completely modeled utilizing computer aided design program AutoCAD in 3-D solid modeling environment and also JIB crane's boom part is generated by using Hypermesh. Then linear static analyses of the finite element model of JIB crane are computed by ABAQUS 6.7.1 solver under certain load combinations and boundary conditions [7].

The material used in the module is steel with a Young's modulus of $E = 207 \text{ GPa}$ and a Poisson ratio of $\nu = 0.3$, and assumed to be isotropic and homogeneous. The models are developed by a CAD computer program and then transferred to the FE package ABAQUS for stress analysis. The total number of elements in Fig. 4(a) is 951, with 775 nodes. As shown in Fig. 4(b), a ten-node tetrahedral element is used to mesh the solid geometry of crane structure [7, 9]. The contour plot of von-Mises stress of the crane boom is shown in Fig. 5(a). Three-dimensional stress distributions of the crane boom bare plotted using von-Mises stress contours, and are shown in

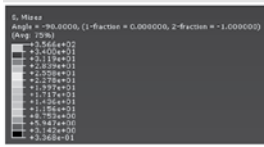
304 MPa. Deflection of the crane boom due to dead load is calculated as 41 mm and from FEA same deflection can be read 40 mm as illustrated in Fig. 5(b). The values of stresses obtained from analytical and finite element methods are compared in Tab. 2.

CONCLUSION

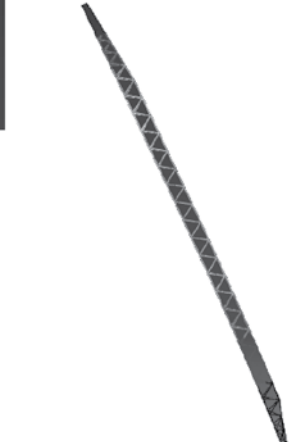
This study adopts the general-purpose FEA software, ABAQUS/Standard operating on an PC to evaluate the stress distribution of the proposed crane structure. In this study, exactly the same stress values (%1-%5 difference) with Finite Element Method was found. Finite element analysis, not only help modifying the areas which are critical in terms of the durability of the structure, but also help the analyzer optimizing the over designed sections and thus simplifying the design. This optimization can be done by considering reliability, weight and material expenditures of the structure and by modifying the structure geometry or narrowing cross-sectional areas.

	Analytical Results	FEM Results
Middle section	34.3 MPa	34 – 31 MPa
Bending due to dead load	33.3 – 16.7 MPa	34 – 19 MPa

Tab. 2: Stress Values



(a) von-Mises stress of the crane boom



(b) Deformation distribution

Fig. 5: Stress and deformation distributions

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GENERATION SIMULATION OF HELICAL GEAR DRIVES BY RACK CUTTERS WITH ASYMMETRIC TEETH

M. C. Fetvacı, C. E. Imrak

Abstract

This study presents a mathematical model of a helical gear set with asymmetric involute teeth, based on gear theory and generating mechanism. The conventional method of tooth-profile shifting is also considered. Furthermore, a computer simulation program is developed to generate the tooth profile of asymmetric involute gears and to illustrate the effect of tool geometry on generated surfaces. This simulation should be helpful in the design and manufacture of asymmetric gears.

Key words

helical gear design, asymmetric involute teeth, modified tool setting, simultaneous gear cutting

Being an essential component of many machines, gears drives are used in power and motion transmission applications ranging from aerospace to high-speed automation, and from missiles to submarines. Due to its advantages of simplicity for manufacture, mesh in line contact, constancy of pressure angle, and insensitivity to central distance variation, involute is the most commonly tooth profile in industrial applications. Vector approach proposed by Litvin [1], enables accurate representation of gear tooth profiles for computer-aided design and finite element modeling. Based on Litvin's vector approach, mathematical models for conventional and modified gear teeth have been presented in [2-5]. Yang proposed a mathematical model of the helical gear with asymmetric involute teeth [5].

For cylindrical gears in applications with uniform load-rotation conditions, an optimised and separate design of traction and thrust flank is desirable. This can be achieved by using different pressure angles for traction and thrust flank which results in asymmetric tooth geometries [6].

In this study, the design of rack-type generating tools (rack cutter or hob) with asymmetric teeth is considered. A common rack cutter is chosen to simulate the simultaneous hobbing process of driving and driven gears. The Long-Short Addendum System is adopted to the given mathematical model for representing the modified tool settings. A computer program is developed to display computer graphs of the helical gears with asymmetric involute teeth.

MATHEMATICAL MODEL OF TOOTH SURFACES

Figure 1 presents the design of the normal section of a rack cutter Σ_n , where regions $\overline{ac}$ and $\overline{bd}$ are the left- and right-side top lands, regions $\overline{ce}$ and $\overline{df}$ are the left- and right-side fillets and, regions $\overline{eg}$ and $\overline{fh}$ are the left- and right-side working regions. In simulating the rack cutter surface for the helical gear generation, the normal section of the rack cutter Σ_n , attached to the coordinate system S_n with its origin O_n , is translated along the line $O_n O_c$ as shown in Fig.1.

Therefore, $\overline{\rho = |O_n O_c|}$ is also one of the design parameters of the rack cutter surface, and β is the helix angle of the generated helical gear.

As shown in Fig. 1, regions $\overline{eg}$ and $\overline{fh}$ of the rack cutter are used to generate different sides of the working tooth surface of the asymmetric helical gears. The symbol m_n represents the normal module. a_c is the design parameter used to determine addendum of the cutter, $b_c = \pi m_n / 4$ half tooth width of the cutter, ϕ_{c1} and ϕ_{c2} are the normal pressure angles. The position vector of regions $\overline{eg}$ and $\overline{fh}$ are represented in the coordinate system S_c as follows:

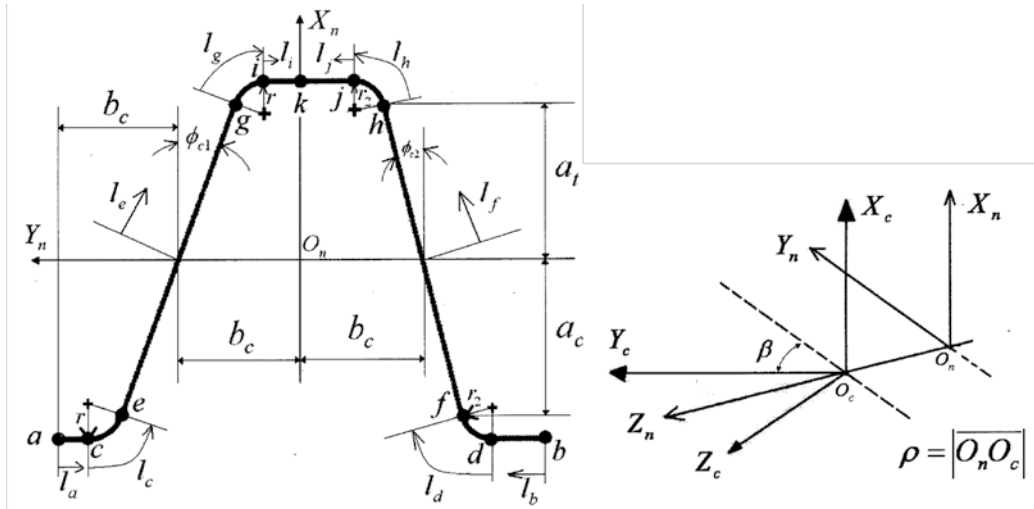


Fig. 1: Formation of rack cutter surface for helical gear generation

$$\mathbf{R}_c^{eg} = \begin{bmatrix} x_c^{eg} \\ y_c^{eg} \\ z_c^{eg} \end{bmatrix} = \begin{bmatrix} l_e \cos \phi_{c1} \\ (b_c - l_e \sin \phi_{c1} + c_y \pi m_n) \cos \beta - \rho \sin \beta \\ (b_c - l_e \sin \phi_{c1} + c_y \pi m_n) \sin \beta + \rho \cos \beta \end{bmatrix} \quad (1)$$

and

$$\mathbf{R}_c^{fh} = \begin{bmatrix} x_c^{fh} \\ y_c^{fh} \\ z_c^{fh} \end{bmatrix} = \begin{bmatrix} l_f \cos \phi_{c2} \\ (-b_c + l_f \sin \phi_{c2} + c_y \pi m_n) \cos \beta - \rho \sin \beta \\ (-b_c + l_f \sin \phi_{c2} + c_y \pi m_n) \sin \beta + \rho \cos \beta \end{bmatrix} \quad (2)$$

where l_e and l_f are the design parameters of the rack cutter surface which determine the location of points on the working surface. l_e and l_f

are limited by $-a_c / \cos \phi_{c1} \leq l_e \leq a_c / \cos \phi_{c1}$ and $-a_c / \cos \phi_{c2} \leq l_f \leq a_c / \cos \phi_{c2}$ for the left- and right-side of the rack cutter respectively.

Fig. 2 depicts the kinematic relationship among the generated gears and the rack cutter. Herein, the coordinate systems $S_c (X_c, Y_c, Z_c)$, $S_h (X_h, Y_h, Z_h)$, and $S_1 (X_1, Y_1, Z_1)$ and $S_2 (X_2, Y_2, Z_2)$ are attached the rack cutter, fixed, driving and driven gear systems, respectively. During the generation process, the rack cutter translates a distance $S = r_{p1}\phi_1$ while the driving gear blank rotates by an angle ϕ_1 and the driven gear blank rotates by an angle ϕ_2 . r_{p1} and r_{p2} represent the pitch radii of the generated driving and driven gears, respectively.

The mathematical model of the generated tooth surface can be obtained by consider-

$$\mathbf{R}_1^i = [\mathbf{M}_{1c}] \mathbf{R}_c^i, \quad (i = ac \sim fh) \quad (3)$$

$$[\mathbf{M}_{1c}] = \begin{bmatrix} \cos \phi_1 & -\sin \phi_1 & r_{p1}(\cos \phi_1 + \phi_1 \sin \phi_1) \\ \sin \phi_1 & \cos \phi_1 & r_{p1}(\sin \phi_1 - \phi_1 \cos \phi_1) \\ 0 & 0 & 1 \end{bmatrix}, \quad \phi_1 = (y_c^i n_{xc}^i - x_c^i n_{yc}^i) / (r_{p1} n_{xc}^i) \quad (4)$$

The locus equations of rack cutter surfaces, expressing in the coordinate system of generated driven gear, can be determined using the

ing the locus equation of rack cutter surface, expressing in coordinate system of the generated gear, and the equation of the meshing. Using the homogenous coordinate transformation from the coordinate system of the rack cutter to the coordinate system of generated gear, the locus equation of rack cutter surface can be attained [1,7].

The locus equations of rack cutter surfaces, expressing in the coordinate system of generated driving gear, can be determined using the homogenous coordinate transformation matrices equation as follows:

homogenous coordinate transformation matrices equation as follows:

$$\mathbf{R}_2^i = [\mathbf{M}_{2c}] \mathbf{R}_c^i, \quad (i = eg \sim jk) \quad (5)$$

$$[\mathbf{M}_{2c}] = \begin{bmatrix} \cos \phi_2 & \sin \phi_2 & -r_{p2}(\cos \phi_2 + \phi_2 \sin \phi_2) \\ -\sin \phi_2 & \cos \phi_2 & r_{p2}(\sin \phi_2 - \phi_2 \cos \phi_2) \\ 0 & 0 & 1 \end{bmatrix}, \quad \phi_2 = (y_c^i n_{xc}^i - x_c^i n_{yc}^i) / (r_{p2} n_{xc}^i) \quad (6)$$

The equation for the tooth profile of the generated driving gear can be obtained by solving Eqs. (3) and (4), simultaneously. According to the Eqs. (1), (3) and (4) the working tooth profile which is generated by region eg of the cutter can be represented. The equation for the tooth profile of the generated driving gear can be obtained by solving Eqs. (5) and (6), simultaneously. According to the Eqs. (2), (5) and (6) the working tooth profile which is generated by region fh of the cutter can be represented. The mathematical model given enables us to obtain the generated pinion and gear simultaneously.

Nonstandard gears are generated by a standardized tool used for generation standard gears but with modified settings of the tool with respect to gear being generated. Undercutting

of the tooth flank can be avoided by the application of the shifted cutter [1]. In this study the Long-Short Addendum System is considered. The absolute values of the cutter displacements $x_1.m_n$ and $x_2.m_n$ are the same but they are performed in opposite directions with respect to the centers of the driving gear and the driven gear, O_1 and O_2 .

When a rack cutter uses a shifted modification, which offsets from the standard pitch, to cut the gear, parameters a_c and b_c of the shifted cutter are affected by the shifted modification. According to Fig. 3, parameter a_c is reduced by $x_1.m_n$ compared with parameter a_c and parameter b_c^* is increased by $x_1.m_n.tan_{\phi_{cj}}$ compared with parameter b_c , as formulated in the following equations.

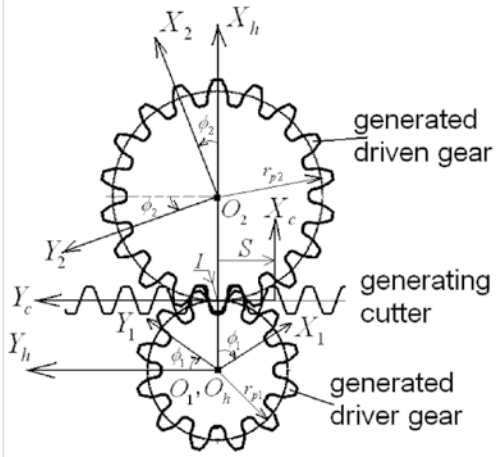


Fig. 2: Coordinate system relationship among rack cutter and generated gears

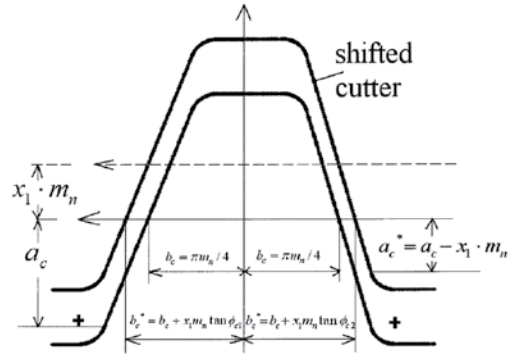


Fig. 3: Normal section of the shifted rack cutter for generating the driving gear

$$a_c^* = a_c \pm x_1 \cdot m_n \quad (7)$$

In equation (25), the upper sign states that it is applied for pinion while the lower sign states

the application to driven gear. The symbol x_1 denotes the addendum modification coefficient.

$$b_c^* = \frac{\pi m_n}{4} + x_1 \cdot m_n \cdot \tan \phi_{cj} \quad j = 1 \text{ or } 2 \quad (8)$$

COMPUTER IMPLEMENTATION

The mathematical models of generating tool and generated surfaces have been given in the previous sections. The profile of the two-dimensional rack cutter can be obtained and expressed on the plane of rotation by treating z_c as a constant. Using the high-level programming language and a commercial graphing software, the complete profile of the gear drive with asymmetric involute teeth surface can be obtained.

Fig. 4 displays an asymmetric gear drive of which pinion tooth is undercut. In this example some of design parameters are, normal module $m_n = 2.5 \text{ mm}$, number of teeth of driving gear $z_1 = 24$, number of teeth of driven gear $z_2 = 96$, pressure angles $\phi_{c1} = 20^\circ$ and $\phi_{c2} = 12^\circ$ and helix angle $\beta = 15^\circ$. Undercutting occurs at the driving gear's flank that has $\phi_{c2} = 12^\circ$ pressure angle. Applying the amount of shifting as $e = 0.4x m_n$ undercutting of this gear is prevented, as depicted in Fig. 4.

CONCLUSIONS

This paper presents generation simulation of conventional helical gear with asymmetric involute teeth. A common rack cutter is chosen to simulate the simultaneous hobbing process of a gear drive. By applying the equations of the profile of rack cutter, the principle of coordinate transformation, the theory of differential geometry, and the theory of gearing, the mathematical model of involute helical gear set is given. The developed program based on the mathematical model of the gear drive is used to obtain computer graphs of generating tool and generated surfaces.

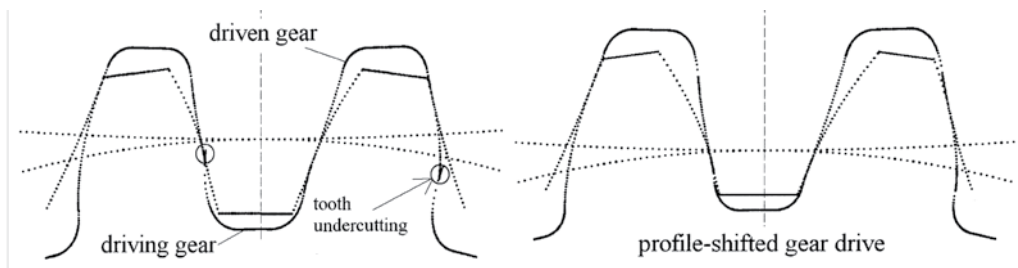


Fig. 4: Transverse section of the standard and profile shifted gear drive

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THE EFFECTS OF THE SHAFT SURFACE ROUGHNESS ON PERFORMANCE OF THE ROTARY SHAFT SEALS

Y. Kerküklü, Z. Parlar, V. Temiz, C. E. Imrak

Abstract

Leakage components play a crucial role in the proper functioning of machines and tools. With the improvement of machine technology, sealing elements should also be improved. The goal of this study is to investigate the effects of surface roughness on performance of radial lip seals made of nitrile, fluorocarbon and silicon rubbers experimentally one by one. This study is divided into two groups of experiments. In the first group, the variation of pressure and seal heat dependent on time are investigated for seals, which operate with diameter of disk 45 mm that have three different surface roughnesses. In the second group, seals are evaluated based on the amount of the oil leakage under 0.5 bars system pressure, and 5 m/s the speed of shafts as considered the working conditions. After 22 hour running, it is noticed that oil leakage of the test rig hardly depends on the grinding direction of surface roughness.

Key words

radial lip seal, surface roughness, leakage, micro pumping effect

The seal function are mainly determined by the surface roughness and surface finishing of running over the shafts and the proper R_a values of radial lip seals are between 0.25 and 0.50 μm . This surface finish will wear away the rubber from the sealing lip and create asperities in the wear track. The asperities support a lubricating film that protects the lip from further wear. If the shaft surface is initially too smooth, the seal lip may not break-in properly and leakage will occur. Although the remarkable lip wear may occur before the protective lubricating film forms and leakage will result, if the shaft surface is initially too rough [1]. There are several types of microgeometric features on the surfaces of lip seals. Elasto-hydrodynamic models of the lip seal have been studied and discussed in [3-6]. These works have been stated that the shaft surface roughness is the main reason for hydrodynamically generating pressure to provide load support and reverse pumping with the maintaining the integrity of the lubricating film. For the automotive industry, a test procedure might be executed with 12 seals from a production batch, each seals being run for 240 hours. Then the batch would be accepted if the total leakage of the 12 seal did not exceed 3 grams and none had leakage greater than 1 gram [2].

Hydrodynamic and elastohydrodynamic analyses demonstrate that shaft roughness and fluctuations on the shaft surface can produce significant effects on lip seal behavior, through hydrodynamic effects [4]. In this study, the radial lip seals composed with nitrile, fluorocarbon and silicon run on the discs with different surface roughness and, the effects of the grinding direction of surface finishing are examined on the oil leakage experimentally.

EXPERIMENTAL SET UP

To investigate the effect of the surface roughness on the performance of the radial lip seals, the test rig as illustrated in Fig. 1 was designed and installed in Laboratory of Machine Design at ITU [7]. In these experiments, radial lip seals were mounted inside the groove of the cover. To prevent the oil leakage between cover and block, an O-ring was placed and high pressure industrial gear oil having 150 cSt viscosity as defined harmonious ISO standard was added. The selected oil density is 897 kg/m^3 at 15 $^{\circ}\text{C}$. This gear oil was heated with two heater installed inside the block up to 60 $^{\circ}\text{C}$ and oil temperature was continuously monitored with thermostat. Inside pressure was also measured by means of a pressure transducer, which can measure between 0 and 2 bars with 2 % precision.

Placing the mixer on the face of the disc has provided to transfer the oil towards all faces of the main body as journal bearing. The developed test system was driven with frequency controlled AC motor whose speed can be ad-

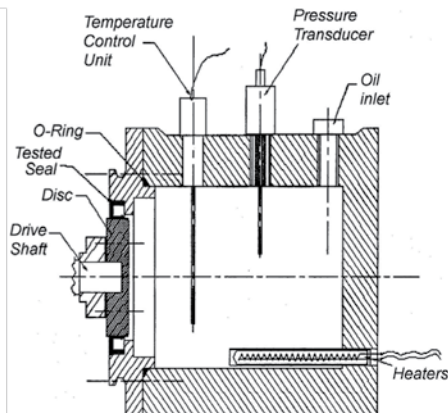


Fig. 1: General view of experimental set up

Diameter (mm)	Rough grinding (left)	Rough grinding (right)	Fine grinding (left)	Fine grinding (right)	Grinding (left)	Grinding (right)
45	2.2	2.1	0.45	0.44	1.1	1.2

Tab. 1: The values of the surface roughness of the discs, R_a [μm]

justed between 0 and 8000 rpm. In low rotation speeds, a belt drive system with 3:1 ratio was used to increase the shaft torque and to get desired velocity values where the radial lip seals are generally used. Rotation speed of the disc was measured by means of an optical tachometer. In this study, fluorocarbon, nitrile and silicon based radial lip seals with 45 mm inner diameter and 72 mm outer diameter were used in developed test system in laboratory conditions. Seat of the seals in the main body has machined with H8 tolerance and its surface roughness as $R_a = 2.5 \mu\text{m}$ [1]. To provide rapid assembly and disassembly the lip seals, the seat has prepared with between 10° and 20° and before the assembly process outer sides of the seal were lubricated, and the seals have forced to sit properly. During the tests, stainless steel discs with 45 mm outer diameter and HRC30 hardness were used. These discs were grinded from left side direction and right side direction to give three different surface roughness orientations. Surface roughness of the discs were measured by means of Mahr perthometer S2 [7] and the values of the surface roughness of the discs are observed and listed as shown in Tab. 1.

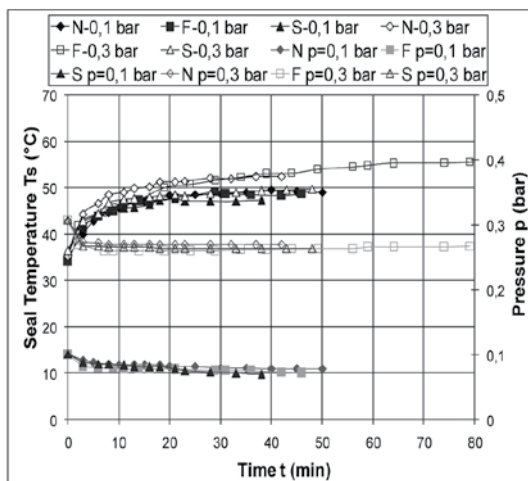
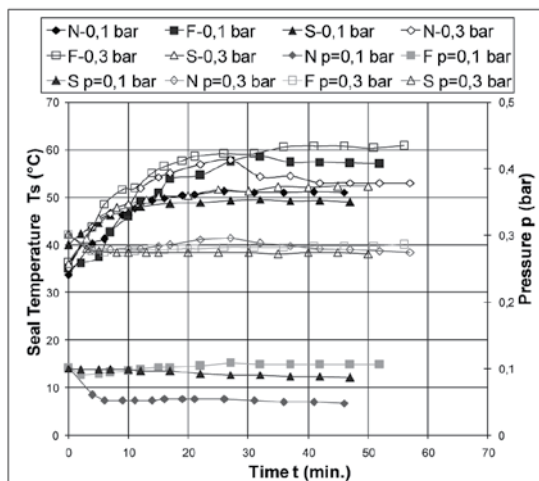
Disc faces where the seals run on are grinded with the ideal values of the surface roughness as indicated in the literature [2-5]. To maintain the geometry of the radial lip seals during the assembly process, disc face has been machined with 0.6 mm radius all around. All the experiments have been executed in between 18°C and 20°C environmental temperature, and between 40 % and 50 % relative humidity in indoor laboratory condition. During the disc installation, the axial eccentricity of disc was eliminated by means of comparator with ± 0.001 mm precision. After slightly lubricating seal lip and disc face, the body of test rig was pushed on the sliding bearing towards the disc. Inside the main body was filled with special gear oil until the oil

reaches the seal, and then the heaters were operated before reaching 60°C oil temperature. In this study, the experimental works consist of two groups. In the first group of tests, discs were run in 3 m/s sliding speed and 0.1 bar and 0.3 bar pressure conditions and then the temperature distribution was recorded. The tests were ended when the inside temperature reaches the steady state value. In the second group of tests, seals were run in 5 m/s speed and 0.5 bar pressure condition 22-hour duration. Oil leakage was measured and it is examined that the surface roughness direction has occurred whether micro pumping effects or not. At the end of each test, seal lips inspected under the microscope to observe the surface cracks and deformations.

RESULTS AND DISCUSSIONS

After 1-hour test, the temperature changes with respect to time and pressure changes with respect to time of seals made of nitrile, fluorocarbon and silicon running on the discs. These discs are ground from right side with $R_a = 0.44 \mu\text{m}$ surface roughness are shown in Fig. 2(a) and running on the discs which are ground from left side with $R_a = 2.2 \mu\text{m}$ surface roughness are shown in Fig. 2(b) separately [7].

During the first 10 minute period, the seal pressure drops for a specific value and then it reaches steady state value for each tested radial lip seals. In addition, during 20 or 30 minute running, the temperature arises and then the temperature reaches nominal value. After the running radial lip seals made of nitrile, fluorocarbon and silicon on the discs having the different surface roughness during 22 hours under 0.5 bar pressure, the values of oil leakage have been measured and these values can be seen in Tab. 2.



(a) ground from right side

(b) ground from left side

Fig. 2: Changes of pressure and temperature with time for three different seals

Grinding Direction	Materials of lip seal	Surface Roughness of shaft R_p (μm)	Leakage (gr)	Contact width (mm)
Right	Nitrile	0.44	1.8327	0.40
		1.2	-	0.30
		2.1	-	0.29
	Fluorocarbon	0.44	1.2778	0.12
		1.2	-	0.13
		2.1	-	0.18
	Silicon	0.44	-	0.35
		1.2	-	0.20
		2.1	-	0.25
Left	Nitrile	0.45	0.0728	0.30
		1.1	-	0.20
		2.2	2.2207	0.33
	Fluorocarbon	0.45	0.009	0.14
		1.1	-	0.12
		2.2	4.6628	0.10
	Silicon	0.45	-	0.31
		1.1	1.8776	0.21
		2.2	-	0.19

Tab. 2: Measured values of the oil leakage after 22-hour running duration

The effective oil leakage may be observed for grinding from right side with low surface roughness, but for grinding left side with high surface roughness. It is also clearly seen that the contact bandwidth is independent to grinding direction. Running the fluorocarbon lip seal on the disc ground from left side, observing the maximum oil leakage on the maximum surface roughness becoming on the narrow contact band can be explained with the effect of the micro-pumping.

After being run 22 hours, 40 times optical micrographs of the tested lip seals made of nitrile, fluorocarbon and silicon are shown in Fig. 3. Small cracks are occurred on the face of the nitrile lip seal. It can be seen that the color changes on the fluorocarbon lip seals and lip of the seal burns. Similarly, the color changes are occurred on the silicon based lip seals.

Elastomeric hardening is one of the important causes of oil leakage. Hardening can be due to excessive contact temperature, but low-cost

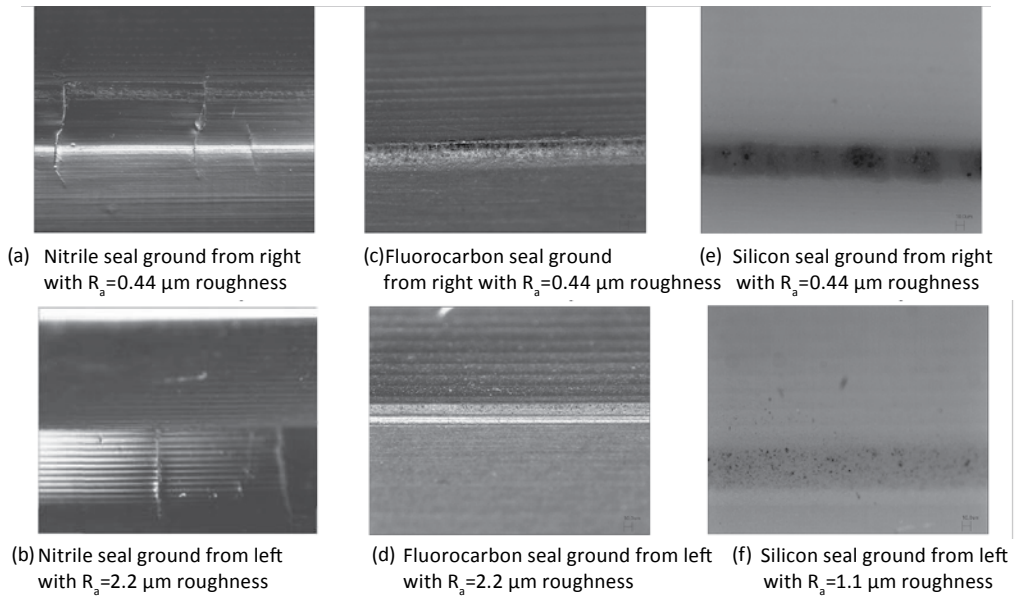


Fig. 3: Optical micrographs of the tested lip seals

materials (NBR, ACM) over heating can also be due to under estimating the sump temperature or frictional heating. Hardening impairs the elasticity and resilience of the lip as well as deforming the micro asperities, weakening the dynamic sealing mechanism. Eventually, embrittlement leads to the formation of small cracks bridging the contact band, creating leakage paths [2].

CONCLUSSION

Regarding all these explanations, the following conclusions can be drawn from the present study:

- The value of inside pressure becomes regime value approximately after 10 minutes and the value of the temperature becomes regime value after 20 or 30 minutes,

- The value of the system oil leakage varies according to grinding direction of the disc surface finishing.
- Small cracks occurred on the nitrile lip seal surface due to heat hardening causes to the oil leakage.
- Contact bandwidth is independent with the surface roughness.

ACKNOWLEDGEMENT

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DESIGN FOR ASSEMBLY AND MAINTAINABILITY IN COMPUTER AIDED ENGINEERING AND A CASE STUDY: PACKAGING

A. Ozdemirkiran, C. E. Imrak, M. C. Fetvacı

Abstract

This study is based on the engineering philosophy which takes into consideration with concurrently to the all product design activities beginning with concept designs until to disposal of product is called concurrent engineering and its some of the most important design tools, design for assembly (DFA) and design for maintainability (DFMt). Application objectives, basic characteristics have been explained and then important criterias of product design processes have been listed. DFMt and Boothroyd&Dewhurst DFA method and using Solidworks 2006 as 3D CAD software some re-design applications has been done to one industrial machine which is used in beverage filling and packaging systems of fruit juice factories are accepted as very important brunch of food industry. It is clearly seen that DFA and DFMt methods asist to get shorter of product design development times, reduce production costs, increase the quality and reliability of the products and reduce maintenance period of times. Renewed designs were compared according to their part numbers, costs, efficiency and reliability.

Key words

concurrent engineering, design for assembly, design for maintainability, Boothroyd and Dewhurst DFA method

Engineering design is a process of developing a system, component, part or process to meet desired needs with a basic meaning. Keeping in mind this main definition and current competitive commercial conditions, the importance of Concurrent Engineering (CE) can be understood better. Beginning from the late '70s, because of improvements in manufacturing and automation systems, Design for Assembly (DFA) and Design for Maintainability (DFMt) have growing importance at design engineering. Both scientific and industrial area, lots of

studies have been done since last 25 years and many articles have been published. The implementations of DFA and DFMt led to enormous benefits including simplification of products, reduction of assembly and manufacturing costs, improvements of quality, reliability and reduction of time to market [1].

This study is focused on CE based design processes and design tools DFA and DFMt. After discussing these design tools' structures and criticizing advantages and disadvantages of

them, an industrial case study will be illustrated. Some subassemblies of one filling and packaging system have been redesigned with the help of Solidworks 2006 as 3D CAD software. Then current designs and new designs have been compared at the point of assembly time, ease of assembly, part varieties and quantities, convenience of maintainability, required equipment quantities and complexity. In this study, Boothroyd and Dewhurst DFA Method have been chosen for evaluation procedure.

DESIGN FOR ASSEMBLY METHODOLOGY

DFA is a systematic method which analyzes product designs to improve assembly easy and reduce assembly time. DFA method can be also

explained by helpful of Design for Manufacturing. The objective of DFM is integration of product design and process planning into one common activity. DFM embraces some underlying principles which help maintain communication between all elements of the manufacturing system and permit flexibility to adopt and modify the design during each stage of the product's realization. DFA as a central element of DFM has one important characteristic and it addresses product structure simplification, since the total number of parts in a product is a key indicator of product assembly quality [2]. This integrated structure of DFA and DFM is illustrated in Fig. 1 [3].

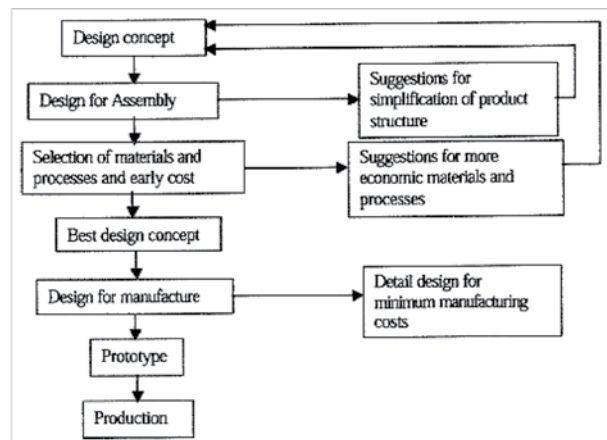


Fig. 1: Typical stages in a DFMA procedure

A number of different DFA methodologies have been developed recently and there are several quantitative evaluation DFA methods. Three best-known and also the most well-documented DFA methods are Boothroyd and Dewhurst DFA Method, Lucas DFA Method and Hitachi Assemblability Evaluation Method [4]. In this study, Boothroyd and Dewhurst DFA Method have been chosen for evaluation procedure. It is a method that uses quantitative evaluation procedures. Design implementations can be carried out using either its handbook or its DFA software. This method can be applied to either

manual assembly systems, special-purpose assembly systems or robot assembly systems. Boothroyd and Dewhurst DFA Method address the problems of to determine the suitable assembly method, to reduce the number of each part that must be assembled, and to get the handling and insertion processes easily [2]. This method has two strong points of consideration. First one is effort of reducing the number of part since saving the functionality of product. If all answers are NO, then the part can be eliminated or combined with the others [5]. Secondly, this method is based on a system of penalties

which for the particular activity, including part's handling, part's insertion and using these penalties a quantitative judgement options can be established. Using the explanations and tables of handbook, each part in the assembly is compared to its handling and insertion situations. The values are collected and it is obtained a total assembly time. Then DFA index of assembly is computed. The DFA index of a product is computed with $EM=AM \times (NM \times TM)$ where EM is DFA Index, AM is basic assembly time for each part, NM is theoretical minimum number of parts, TM is total assembly time. EM can be accepted as 3 s. as generally. Different implementations can be used different basic assembly times. However; it provide an accurate relative comparison between design choices [5].

DESIGN FOR MAINTAINABILITY METHODOLOGY

Machines are designed to perform their intended functions as long as possible but it doesn't mean that the machines can work forever. During this period, the components of machines can normally fail and then these parts are repaired or replaced with new one. When the machines or systems fail, if there are no any definite maintenance instructions, the operator applies some sequential actions which extend total maintenance

time and increase cost. There are 2 main concepts in maintenance task, these are reliability of systems and maintainability. Reliability has been defined as the probability of failure free system or equipment operation during a prescribed time period and under specified conditions. Successful operation for a specified period of time and mean time between failures are 2 important measuring detail for reliability [6]. Maintainability is defined as the probability that a failed system can be repaired in a specific interval of downtime. The basic objectives of DFMT to assure that the product can be maintained throughout its useful life-cycle at reasonable expense without any difficulty [6].

CASE STUDY: PACKAGING

It has been chosen a subassembly of one beverage filling and packaging system as a case study. Fruit juice packages are filled with pasteurized product and packaged under sterilized and closed conditions using roll shaped packaging board which is got by board suppliers. It is not an easy process. One sequential process scheme of one filling and packaging system is shown in Fig. 2. Taking into consideration of Boothroyd and Dewhurst DFA Method and DFMT Method some certain applications have been redesigned using Solidworks 2006 as 3D CAD software.

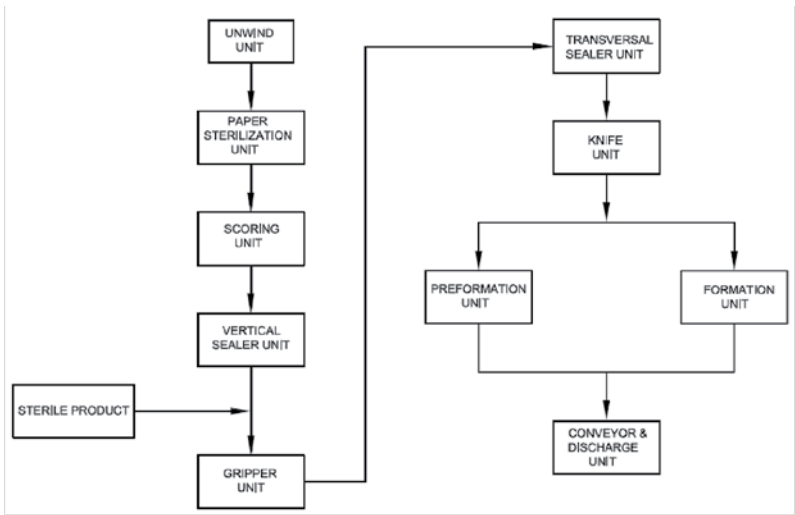
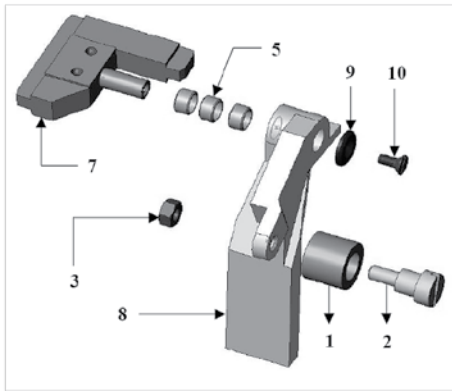
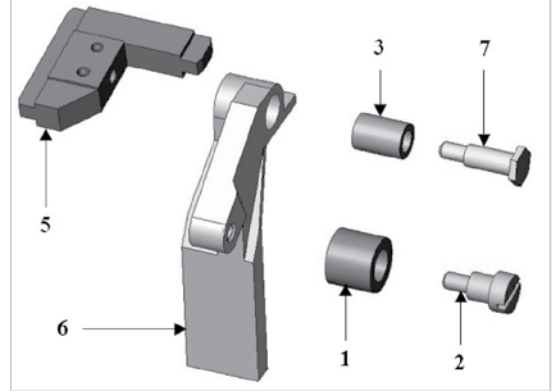


Fig. 2: Flowchart of a filling and packaging system



(a) Current design



(b) New design after DFA and DFMT

Fig. 3: Packaging expeller

The product is pushed to exit of machine with help of expeller subassembly group after finishing filling and formation processes. This group follows a certain route with a guide chain. Exploded view of current design and new design after DFA and DFMT are depicted in Fig. 3.

The part shown with number 7 is the main support of subassembly and the holes which stay up to this part is for chain connection links. Number 8 is fixed onto number 7 with screw by guidance of welded pin. As time passed, the length of chain gets longer and loses its tightness. Because of this problem and some other bad mechanical contacts and situations, some extra forces occur onto some parts like welded pin. These forces can destroy or broke that pin. To maintain it, whole subassembly must disassemble from chain which is not an easy action. Tab. 1 explains the DFA evaluation of current design and new of packaging expeller subassembly. After examining the current design and evaluation table, it was understood that the small parts and some unnecessary fastening parts cause assembly difficulties as physically and mechanically. It was not also easy to maintain these parts so it was decided to redesign.

Because of difficulties about assembly, disassembly and maintenance of current design, the subassembly has been redesigned considering principles of DFA and DFMT methods. Firstly, the welded pin that can be broken easily was divided from the main support. In case of the

pin is bent, there is no need to disassemble all group and threaded pin will only be changed. Multi pieces bushings' design was changed and then unnecessary fastening parts like nut, washer were eliminated so that total quantity of parts were reduced. After redesign the subassembly according to DFA and DFMT principles, the DFA index increased from %12.9 to %23.9. Total number of parts were reduced from 10 to 6.

Total assembly time and cost were also reduced about %46. On the other hand, material and manufacturing costs were reduced approximately from € 144.50 (259.70 YTL) to € 139.00 (250.30 YTL). These are summarized in Table 2.

CONCLUSIONS

In this study, the effects of DFA and DFMT to design of product have been searched in details. Their methodologies have been explained, advantages and disadvantages of using these methods have been discussed. As a case study, application of DFA and DFMT principles on packaging systems have been conducted. Important improvements have been obtained like reduction in assembly costs, part quantities, manufacturing costs, designing more easy structures, increasing quality and reliability. These results show the importance of using DFA and DFMT methods in product design.

Part Number	Part Name	Part Repetition	Manuel Handlig Code	Manuel Handlig Time (s)	Manuel Insertion Code	Manuel Insertion Time (s)	Total Assembly Time (s)	Manuel Assembly Cost	Minimum Part Number
1	Guide Part	1	10	1.50	06	5.50	7.00	0.02	1
2	Bolt	1	10	1.50	38	6.00	7.50	0.02	0
3	M6 Nut	1	01	1.43	38	6.00	7.43	0.02	0
4	Orientation	1	-	-	98	9.00	9.00	0.03	-
5	Bushing	3	01	1.43	31	5.00	19.29	0.06	1
6	Orientation	1	-	-	98	9.00	9.00	0.03	-
7	Main Support	1	10	1.50	31	5.00	6.50	0.02	1
8	Package Expeller	1	10	1.50	16	8.00	9.50	0.03	1
9	Washer	1	11	1.8	06	5.50	7.30	0.02	0
10	M4 Bolt	1	16	2.57	39	8.00	10.57	0.03	0
TOTAL							93.09	0.28	4
DFA Index = $4 \times 3 / 93.09 = \% 12.9$									

Tab. 1: DFA evaluation of packaging expeller subassembly
(a) current design

Part Number	Part Name	Part Repetition	Manuel Handlig Code	Manuel Handlig Time (s)	Manuel Insertion Code	Manuel Insertion Time (s)	Total Assembly Time (s)	Manuel Assembly Cost	Minimum Part Number
1	Guide	1	10	1.50	06	5.50	7.00	0.02	1
2	Bolt	1	10	1.50	38	6.00	7.50	0.02	0
3	Bushing	1	00	1.13	30	2.00	3.13	0.01	1
4	Orientation	1	-	-	98	9.00	9.00	0.03	-
5	Main Support	1	10	1.50	31	5.00	6.50	0.02	1
6	Package Expeller	1	10	1.50	16	8.00	9.50	0.03	1
7	Threated Pin	1	10	1.50	38	6.00	7.50	0.02	0
TOTAL							50.13	0.15	4
DFA Index = $4 \times 3 / 50.13 = \% 23.9$									

(b) new design

	Part Number	Total Time (s)	DFA Index	Assembly Cost (YTL)	Material & Manufacturing Cost (YTL)	Total Weight (kg)
Current Design	10	93.09	%12.9	0.28	259.70	0.65
New Design	6	50.13	%23.9	0.15	250.30	0.69

Tab. 2: Comparison of two designs

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MEASURING OF CREEP OF CEMENT PASTE WITH OPTOELECTRONIC PROBE

P. Padevĕt

Abstract

Basic creep is one of major value used for computer modelling of creep of cement paste. Incremental linear optoelectronic probe is used for long term measuring of change of specimen length under constant load. By 3 probes are possible get values of displacement from measuring. Small specimens made from cement paste are tested in the loading equipment for compression. Specimen is cylinder with diameter 10 mm and height 70 mm. 3 probes are placed between loading for measuring of the axial deformation of the specimen. Specimen is loaded by stationary load during time of the test. Length of the test is probably 1 month. Changes of displacement from 3 probes are continuously storage into the computer. Deformation of the specimen is average value from probes. On the specimens are measured deformations in the time for dry specimens and for full water saturated specimens. Data from measuring are used for computational modelling of material.

Key words

cement paste, creep, probe, cement specimen

Correct mathematical prediction of concrete creep and shrinkage inevitably requires understanding of the underlying physical mechanisms. It is generally accepted that drying shrinkage is caused by capillary tension, solid surface tension, and withdrawal of hindered adsorbed water and interlayer water from cement gel. Additional shrinkage, called autogeneous, is produced by chemical volume changes (which could be expansive) and self-desiccation. As for creep, many mechanisms causing creep or influencing it have been proposed and studied.

In structures of medium and large thickness, drying is a relatively shallow phenomenon for a very low time. For a concrete of average strength (and thus permeability), the depth affected at the end of 15 years is less than 20 cm. Now all tests show a large difference, both in shrinkage and in creep, between the behaviours that occur during drying and those that occur in the absence of any exchange of moisture.

In these conditions, the question that an engineer faces is: is it more realistic to model the behaviour of the structure extrapolation from experimental results obtained on small

specimens (by statistical regression on thickness parameter) or to treat the structure as a multi-layer composite? In this latter approach, the internal layer, at least up to a certain age (an age that is proportional to the square of the thickness), is exposed to the conditions of the test without drying. It should be noted that this later approach also provides information about the transverse distribution of stresses in the structure.

Such an approach cannot, of course, solve all problems, and remains to be extended and validated. But in the absence of a quantitative of Pickett's paradox, it can already be used to deal pertinently with some problems.

The small section of the specimens tested makes it possible to conclude that the experimental shrinkage and creep values obtained under these two extreme conditions bracket the behavior under service condition.

SPECIMENS

Specimens were made in the plastic mould equipment. All specimens for test were of cylindrical shape, with 10 mm in diameter and 70 mm in length. Each mould contains 7 cylindrical specimens. The length of specimens in the mould is 120 mm. Cement paste is after filling the moulds vibrated by knocking the mould. From specimens made in the mould are saw

specimens for shrinkage test and for material properties tests. Length of the specimens for shrinkage test is 70 mm, and length of the specimens for material testing is 20 mm. From one specimen of mould are saw 3 specimens for material testing.

SYSTEM OF MEASURING

Measuring of shrinkage is realized by optoelectronic probes SM12, working on principle change of measured deformation on the electric pulses. Number of pulses is calibrated with change of position. Accuracy of optoelectronic probes is 0.001 mm on length 12 mm. Sensitivity of probes is 0.1 μm . Signals from probes are on the "other side" firstly transfer by receivers RS422 to the level TTL. After then are signals processed by 32 bit programmable squaring counter. Measured data are imported by RS 232 to computer, where are archived. For measuring of creep on the 70 mm length specimens are used 3 optoelectronic probes. Probes were used in the lever mechanism (Fig. 1).

Measuring of the material properties are realized in the MTS Alliance RT30 equipment. By this equipment are tested: strength, Modulus of Elasticity. From every one 120 mm length specimen are sawed 3 specimens marked A, B, C.



Fig. 1: Measuring equipment

From compression test we get compression strength, Modulus of Elasticity. Both values may be different from one basic specimen with 120 mm length. Value of the properties may be different from top of the specimen compared to properties from the bottom part of the specimen.

RESULTS

Firstly were tested material properties of cement paste. Cement paste was prepared from type of Portland cement CEM I 42,5R. Water–cement ratio was 0.5. Specimens were prepared 1 year ago and place half of year in the water basin. After then were except from basin, and leaved in environment with temperature 20 °C and 50 % humidity.

Five specimens 120 mm length were tested. Every specimen was sawed to 3 small specimens with depth 20 mm. From compression tests were measured next results. Average strength of the top parts of 120 mm length specimens was 63.4 MPa. From central parts of specimens was achieve average strength 66.2 MPa. Finally, bottom part of the specimens was characterized by average strength 65.1 MPa (Fig. 2).

Secondly was measured creep (Fig. 3,4) by measuring equipment. Specimen was placed into the lever mechanism and loaded at 942 N. It is 11.99 MPa. Load level matching about 20 % of strength of specimens.

CONCLUSIONS

18 specimens were tested for getting the material parameters of cement paste. Average strength of cement paste was 64.9 MPa. Properties of cement paste are similar by depth of 120 mm specimen.

Lever mechanism is suitable equipment for testing the creep. Level of loading was about 20 % of cement paste strength. Temperature in closed room was from 21.5 to 22.3 °C. Creep of specimen achieved 40 µm after 3 days.

ACKNOWLEDGEMENT

This outcome has been achieved wit financial support of the GACR, project No. 103/08/1642; Virtual testing of concrete creep.

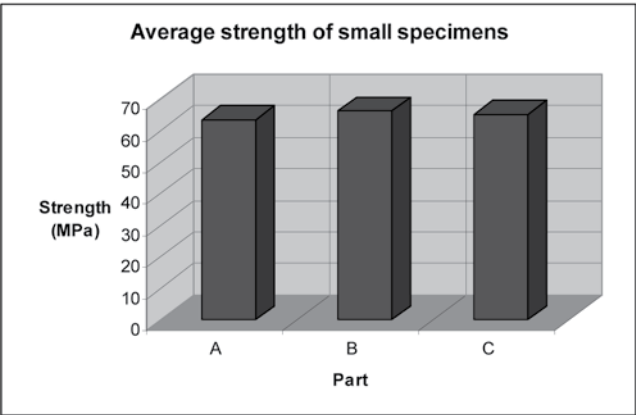


Fig. 2: Strength of specimens

Creep

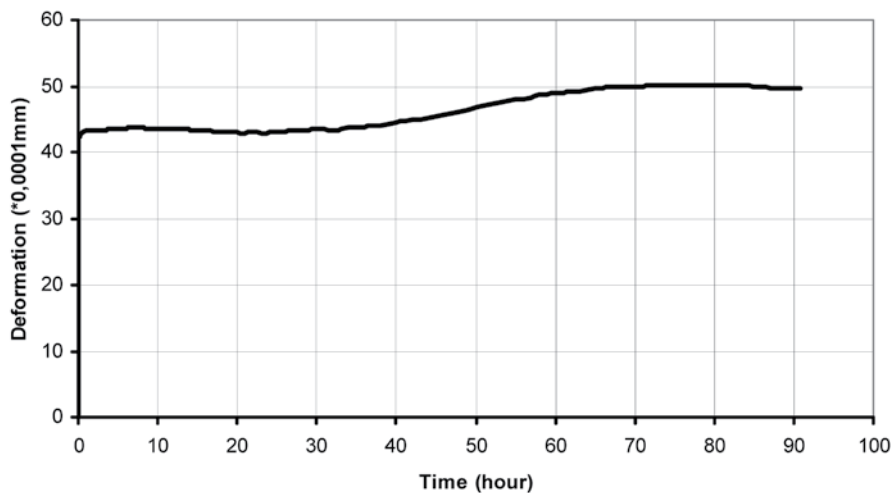


Fig. 3: Shrinkage of the specimen

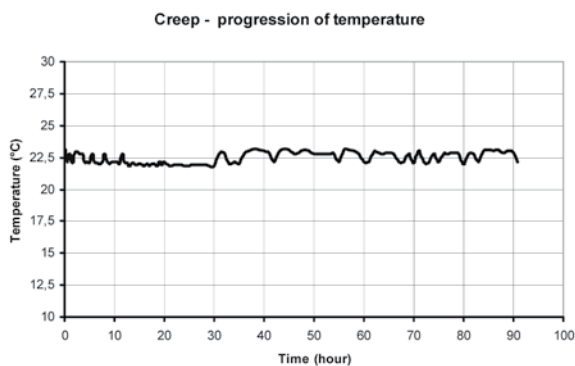


Fig. 4: Progression of temperature

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P. Jonšta, P. Váňová, J. Malcharcziková

Abstract

Compacts discs are optical recording media used to store digital data. They are on the market more than twenty-five years and were made originally for storing digital audio. Expansion of computer engineering in 1990s started forceful development of compact discs in this field. European countries consume annually several millions of compacts discs. Increasing volume of generated electronic waste resulted of the trend. Discarded discs are not recycled at present and they are dumped or destroyed at incinerators. Discs may at the waste dump contaminate soil by heavy metals and incineration of these discs may release toxic substances.

Metallographical analysis was carried out on compact discs of prestigious firms, for example VERBATIM and MEMOREX. All had storage capacity 700 MB or if you like 80 minutes. Discs were composed of several layers of various materials. Metals of layers included may have unfavourable impact on environment.

Key words

compact discs, metallographical analysis, electronic waste

Compact discs became one of the most extent optical device for digital data storage during the last quarter-century. Originally they were developed to store digital music but the massive development of the Information Technologies in 90th of the last century launched huge boom of the compact discs in this field. Nowadays, the number of consumed compact discs fluctuates around million of pieces in european countries only. The obvious consequence of this immense consumption is enormous increase of electronic waste as well. Discarded discs are not recycled at present and they are dumped or destroyed at

incinerators. Discs may at the waste dump contaminate soil by heavy metals and incineration of these discs may release toxic substances.

TECHNICAL SPECIFICATION OF COMPACT DISCS

CDs have compact dimensions. Diameter of disc is 120 mm (especially 80 mm) and thickness is 1.2 mm. Weight is about 18 g. The matrices of all compact discs consist of polycarbonate which includes several layers made from different materials. Data are digitally recorded

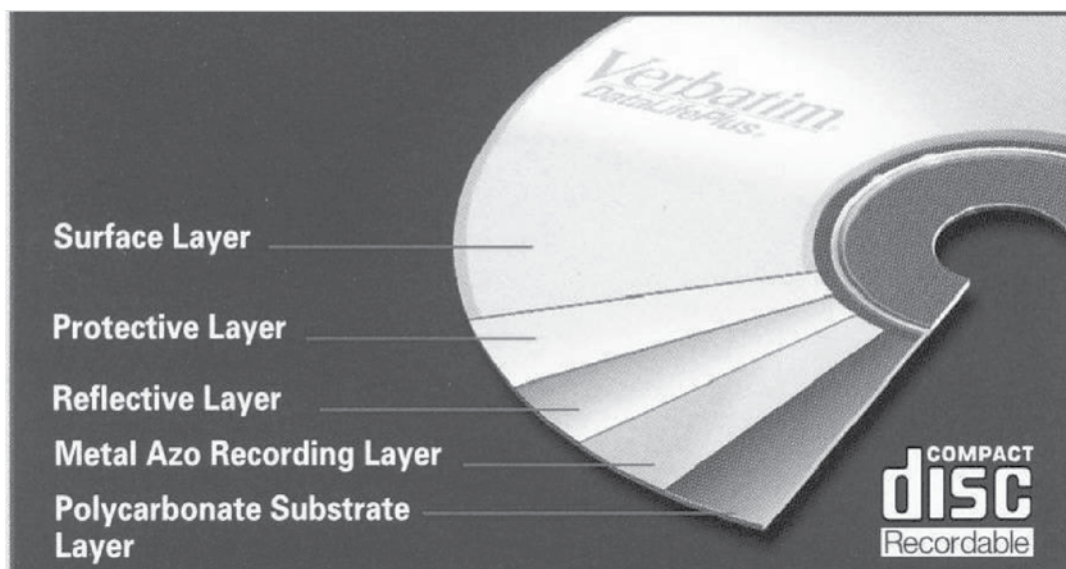


Fig. 1: Layers of chosen CD-R disc made by VERBATIM

into a recordable layer by laser ray heat which contains typical dye (Cyanine, Hybrid Cyanine, Metallized Azo,...) based on the licence owned by given manufacturer. The recordable layer is covered from upside down with a metallic reflective layer made of alluminum, silver or gold and as a protection against damages it is protected by a film of lacquer. The resultant color of the bottom side of the compact disc is obtained by combination of the recordable layer dye and reflective layer dye [1]. The discs can also contain other layers, i.e. layers for printing by LightScribe. Fig. 1 shown layers of compact disc CD-R made by VERBATIM.

Lifespan of burned compact discs in comparison with originally pressed discs is relatively short and is influenced by wide range of factors. First, there could be manufacturing defects, i.e. faulty sealing of single layers which causes the pervasion of oxygen into the metallic layers and their corroding. Next important aspect is the quality and wrong handling of burned device (such as storage, the way of usage etc.). Based on above mentioned factors and depending up the quality of the device, the lifespan of burned CDs ranges from 2 to 5 years [2, 3]. What to do with not readable discs is the question which

arises as well. The thickness of reflective layer, which the most frequently contains aluminum, is 100nm and its volume is 0,01g. By consumption of 3488 mil. of CDs in European Union in 2005 we get the number 34 880 tons of aluminum. How to answer the question about the waste disposal in satisfying way is ambiguous. There are 2 divers theories. The first one encourages people to throw CDs away to the container for mixture waste and to proceed them for downcycling. The second one says that this type of waste can not be used because of metallic reflective layers and that it only belongs to mixture waste [4].

METALLOGRAPHICAL ANALYSIS OF COMPACT DISCS

Metallographical analysis was carried out on compact discs of prestigious firms, for example VERBATIM and MEMOREX. All had storage capacity 700 MB or if you like 80 minutes. The aim of the thesis was to reveal the layers of selected discs, their analysis and consequential comparison. The analysis of single layers was not satisfying and that is why the aim of the thesis was not met in full. All macro pictures were taken

by digital camera OLYMPUS C-765 UltraZoom (Fig. 2a,b). Samples of selected discs for metallographic analysis were cut manually (figure 2b) and the analysis was done by mechanical grinding and polishing in transverse direction

of the samples. Observation of the layers and their photos were taken by optical microscope ZEISS NEOPHOT 32 (the part of the microscope is a digital camera DP 11). The single layers of selected devices are shown on Fig. 3, 4.

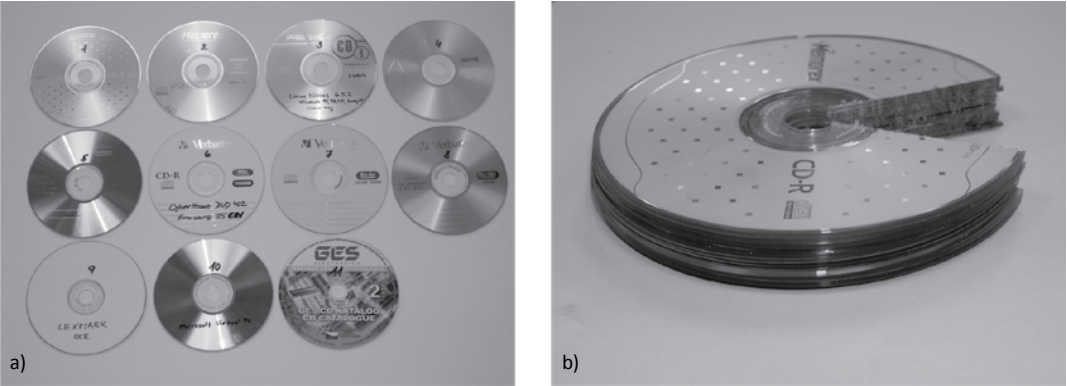


Fig. 2: Macro pictures of compact discs using for analysis (No. 1 -11)

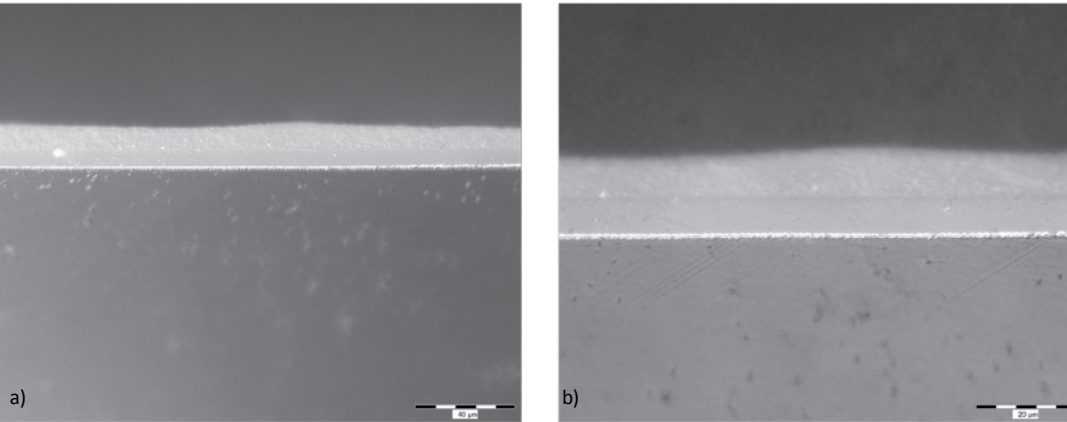


Fig. 3: Layers of compact disc No. 2 – MEMOREX Music CD-R 80 min

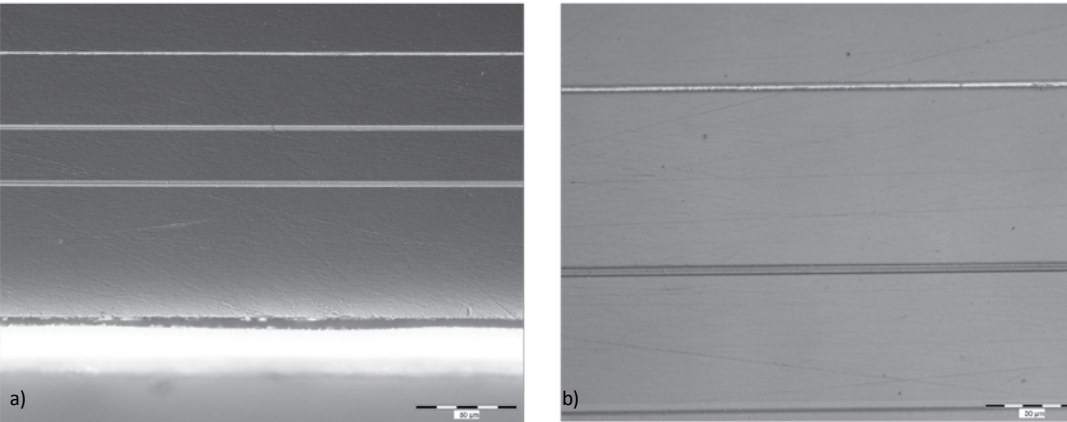


Fig. 4: Layers of compact discs No. 9 – VERBATIM Super AZO Printable 700 MB

CONCLUSION

The thesis is focused on metallographic analysis of layers of compact discs CD-R produced by different manufacturers. The layers of all observed discs contained metallic particles. Not readable discs caused by this fault are not currently recycled in the Czech Republic. The best waste is the one which does not arise at all. That is why the recycling of discs is losing its importance now when such a fast development of new technolo-

gies appears. It becomes common to use fit-up devices such as flash cards or external discs for example.

ACKNOWLEDGEMENTS

This work was realized under the support of the research projects No. MSM 2E06008 (Ministry of Education of Czech Republic).

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STRUCTURE AND MECHANICAL PROPERTIES OF CR – MO – V CAST STEELS AFTER REGENERATIVE HEAT TREATMENT

G. Golański, J. Kupczyk

Abstract

The paper presents results of research on the influence of regenerative heat treatment parameters on structure and properties of Cr – Mo – V cast steels after long-term operation. Performed research have proved that by means of regenerative heat treatment it's possible to obtain mechanical properties similar to the properties of new casts. It has been concluded that in the case of investigated cast steels bainitic structure after tempering guarantees high mechanical properties and impact energy. Structures with prevailing ferrite content were characterized by impact energy of KV > 27J and mechanical properties similar to those after service.

Cr – Mo – V cast steel, regenerative heat treatment, bainite, mechanical properties

During long term operation of steel casts under creeping conditions the developing changes in microstructure contribute to a decrease of their mechanical properties and impact energy in particular [1 ÷ 3]. Self study [4] has revealed that the smallest decrease of impact energy after long term service was observed in cast steels with bainitic structure or bainitic one with slight ferrite amount of ca. 5%.

However, changes of the cast steels' mechanical properties do not limit the possibility of their further safe operation. Extension of service time of steel casts is achieved through the process of their revitalization. Such a process consists in regenerative heat treatment whose aim is to increase plastic properties (impact energy, decrease of NDT temperature) [5].

Currently applied heat treatment of the steel casts contributes to obtaining of a structure with prevailing ferrite content on the level of: $80 \div 90\%$. Such a structure ensures required impact energy $KV > 27J$ and mechanical properties comparable to the ones after service [6, 7].

The aim of this work is to show that bainitic structure, in comparison with ferritic – pearlitic or ferritic – bainitic one, ensures the most favourable combination of high mechanical properties and impact energy in the steel casts.

MATERIAL FOR RESEARCH

Material under investigation was low alloy cast steel: G21CrMoV4 – 6 (G21) i G17CrMoV5 – 10 (G17). Samples for research were taken from internal frame of steam turbines serviced for around 186 000 hrs at the temp. of 540 °C, pressure 13.5Mpa; and 252 000 hrs at the temp. of 535°C, pressure 9MPa for G21 and G17 cast steels, respectively. Chemical composition of the investigated cast steels is presented in Tab. 1.

METHODOLOGY OF RESEARCH

Critical temperatures A_{c1} and A_{c3} of the investigated cast steels, which were measured by dilatometric method, amounted for the respective cast steels to G21: 775 and 903 °C and for G17: 809 and 937 °C. Heat treatment of the investigated cast steels consisted in austenitizing (4hrs) at the temperatures of 910 °C (G21) and 960 °C (G17) and subsequent cooling at the rates corresponding to: bainitic hardening or full annealing. Tempering (4hrs) was performed at the temp.: $690 \div 730$ °C (G21) and $700 \div 740$ °C (G17). After full annealing the G21 cast steel was subject to holding at $(\alpha + \gamma)$ range (4hrs) at the temp.: $780 \div 840$ °C. Applying of $(\alpha + \gamma)$ annealing instead of tempering for G21 cast steel was determined by the necessity to ensure required impact energy. This issue has been precisely described in another paper work [8]. Observations and record of microstructures was done

Investigated material	C	Mn	Si	P	S	Cr	Mo	V
G21CrMoV4 – 6	0.19	0.74	0.30	0.017	0.014	1.05	0.56	0.28
G17CrMoV5 -10	0.15	0.65	0.26	0.012	0.018	1.60	1.17	0.30

Tab. 1: Chemical composition of the investigated cast steels, %wt

by means of JOEL JSM – 5400 scanning microscope. Research on mechanical properties was carried out according to currently respected norms.

SELF RESEARCH

Post operational condition

In the post operational condition the G21 cast steel revealed degraded ferritic – pearlitic structure with numerous carbide precipitations located on grain boundaries and inside ferrite grains. Carbides precipitated on grain boundaries after formed „continuous grid“ of precipitates. While in pearlite grains there were the following processes observed: spheroidization and coagulation of carbides (Fig. 1a).

The G17 cast steel in post operational condition was characterized by bainitic – ferritic – pearlitic structure. On grain boundaries and inside ferrite grains there were numerous carbide precipitations observed and their morphology was diverse. In some places the number of carbides precipitated on grain boundaries was so large that they formed „continuous grid“ of precipitates. On boundaries of bainite needles there were numerous plate-like and spheroidal carbides noticed (Fig. 1b).

Properties of the investigated cast steels after long term operation along with the standard requirements are presented in Tab. 2.

Structure of the investigated cast steels after heat treatment

Slow cooling after austenitization process (full annealing) with subsequent ($\alpha + \gamma$) annealing (G21) and high-temperature tempering (G17) enabled obtaining of:

- in the G21 cast steel: ferritic – pearlitic structure with prevailing content of quasipolygonal ferrite and numerous carbide precipitations inside and on grain boundaries along with visible degradation of pearlitic areas (Fig. 2a);
- in the G17 cast steel: ferritic – bainitic structure. Inside ferrite grains, apart from fine-dispersion carbides, there were also numerous spheroidal precipitations observed. Amount of bainite in the structure did not exceed 15%. On grain boundaries there were numerous, big precipitates of carbides noticed (Fig. 2b).

Bainitic hardening and high-temperature tempering in the investigated cast steels allowed to obtain the structure of high tempered lower bainite with numerous carbide precipitations.

Mechanical properties after heat treatment

Tempered/annealed structures of the investigated cast steels obtained after slow cooling are characterized by required impact energy

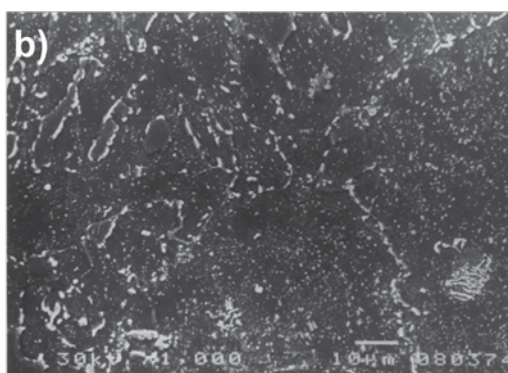
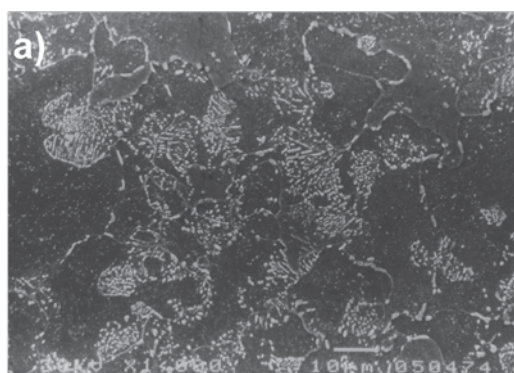


Fig. 1: Structure of the cast steel after service: a) G21; b) G17

amounting to ~40J for G21 and ~ 60J for G17 cast steel. Mechanical properties of the casts were on the level of those after service (Table 1 and 2). Tensile strength of the cast steels after heat treatment was lower by ca. 7 ÷ 13% in comparison with the required minimum of 590MPa. The G21 cast steel met the requirements concerning yield point, however, the yield point of the G17 cast steel was lower by ca. 40% than the minimum requirements (Tab. 3).

The results of tempering of bainitic structures in the investigated cast steels were as follows:

- in G21 cast steel: tempering at the temp. of 690 °C contributed to obtaining of impact energy on the level of 68J with hardness of 255HV30. Elevation of tempering temperature up to 710 °C (maximum recommended by the standard) and up to 720 °C and 730 °C causes further increase of impact energy to the level of 92, 104 and 131J, respectively. Along with the impact energy increase there

was also slight hardness decrease of ca. 12% in comparison to that after tempering at 690°C (Fig. 3a and b, Tab. 3);

- in the G17 cast steel after tempering at the temp. of 740 °C (maximum temperature of tempering for this grade) almost twofold increase of impact energy can be observed in comparison with the one obtained at 700 °C. Together with the impact energy increase there was also ca. 15% decrease of hardness. Similar tendency could be noticed in the case of yield point and tensile strength. (Fig. 3c and d, Tab. 3).

CONCLUSIONS

- Tempered/annealed intercritical structures with prevailing content of ferrite, obtained as a result of slow cooling, ensure required impact energy of KV > 27J and mechanical properties comparable to those after service.

		TS MPa	YS MPa	El. %	KV J	HV30
G21	After service	545	305	26	10	156
	Polish Norm ¹	590 ÷ 780	min. 320	min. 20	27	140 ÷ 227*
G17	After service	491	241	14.4	12	133
	Polish Norm ²	590 ÷ 780	min. 440	min. 15	27	---

1) PN – 89/H – 83157; 2) PN – EN 10213 – 2; * - hardness according to Brinell

Tab. 2: Mechanical properties of G21 and G17 cast steel after service

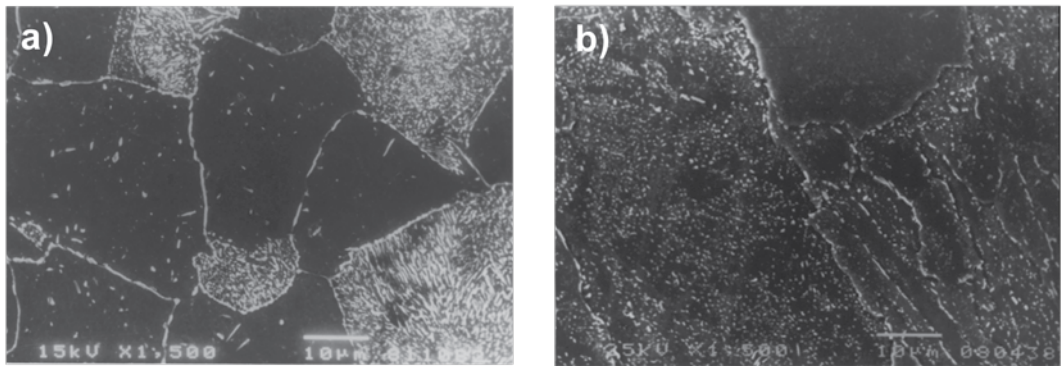


Fig. 2: Structure of the cast steels after slow cooling and annealing (a) – G21 and tempering b) G17

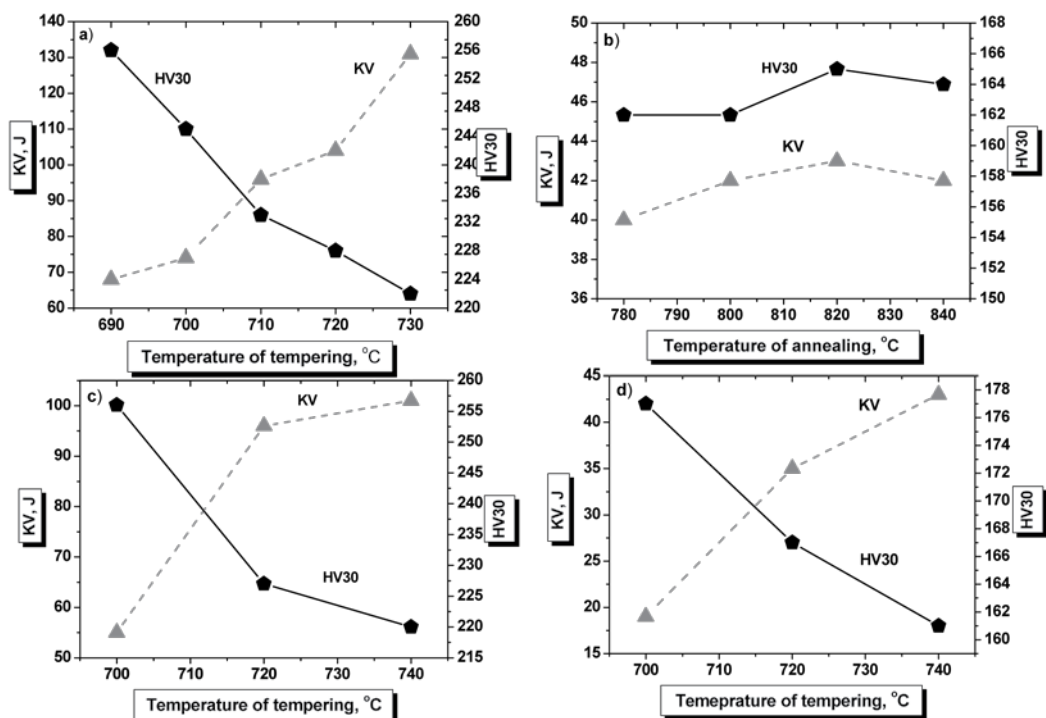


Fig. 3: Influence of tempering temperatures and annealing on the cast steel properties: a, b) G21; c, d) G17

Material	Sort of heat treatment		TS MPa	YS MPa	El. %	KV J	HV30	Structure
G21	Bainitic hardening	720	728	620	18	104	228	bainitic
		730	702	583	22	131	222	
G17		700	794	606	17	55	256	
		740	675	486	19	101	220	
G21	Full annealing	800	552	316	31	42	162	ferritic - pearlitic
		840	550	324	28	42	164	
G17		720	548	274	23	60	168	ferritic - bainitic
		740	517	269	25	62	167	

Tab. 3: Structure and properties of the cast steels after heat treatment

- Bainitic structure allows to apply high temperatures of tempering > 710 °C without any concern that mechanical properties might decrease below the required minimum. High temperature of tempering increases the cast steel structure stability after long term service at elevated temperatures.
- Tempered bainitic structure ensures optimum combination of high mechanical properties and impact energy of KV > 100J.

ACKNOWLEDGEMENT

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GUNSHOT WOUNDS – CONTRIBUTION TO THE BIOMECHANICAL ANALYSIS

S. Mehremic, I. Karabegovic

Abstract

Wound ballistics is the part of terminal ballistics dealing with what happens when a bullet strikes a living being. It is characterised by very rapid events, high pressures and great deformation rates. Significant amount of work has been done in the military domain to better understand the wound ballistic phenomena associated with a bullet penetrating a human body. This paper describes the penetration behaviour of bullets and fragments in the human body from a mechanical and biologi-

cal point of view. It also introduces the basic sciences of wound ballistics and gives the overview of the tissue simulants. The effects of small arms ammunition on the base of wound profiles are compared.

Key words

wound ballistics, permanent cavity, temporary cavity, penetration depth

Terminal ballistics is the science of projectile behaviour in the target and wound ballistics the part of terminal ballistics dealing with what happens when a bullet strikes a living being. It is characterised by very rapid events, high pressures and great deformation rates.

A bullet must have a significant amount of kinetic energy to reach the target, penetrate into it and perform its task. The task for law enforcement is not to kill or even to injure but to stop an offender from continuing to pose an imminent grave danger to the health and life of others. Unfortunately, however, the outcome will often be a serious injury or death of the offender. This fact, however, must not stop us from trying to avoid superfluous and unnecessary injury in the spirit of the International Law and Human Rights.

TERMINAL BALLISTICS

A bullet impacting the target has an impact mass of m_i (g) and velocity v_i (m/s). Its kinetic energy E_i (J) is defined as:

$$E_i = 0.5 * m_i * v_i^2 / 1000 \quad (1)$$

Impact energy E_i is partially dissipated into the target and performs work upon it. From (1) we can see that velocity determines the amount of kinetic energy. If the energy isn't dissipated into the target, it's used somewhere else. The wound ballistic energy equation can be expressed as:

$$E_r = E_i - E_{def} - E_d \quad (2)$$

where E_r is the residual kinetic energy, E_i the impact energy, E_{def} the energy used by bullet deformation and E_d the energy dissipated into the target tissue. Since E_i has to be significant, E_{def} and E_d must be maximised in order to minimise E_r . The residual energy is a significant factor describing the danger to bystanders when the bullet completely penetrates and exits the primary target continuing its flight.

Kinetic energy dissipation (E_d) can be increased by bullet instability, deformation and fragmentation. This increases the cross-sectional area in the direction of penetration which increases the dissipation of kinetic energy. The precise depth at which tumbling occurs is difficult to predict as it depends on the yaw angle on impact, properties of the tissue encountered and internal instabilities of the bullet.

Controlled deformation can in principle be achieved by a cavity in the tip of the bullet. Some typical expanding bullet constructions are:

1. conventional hollow point,
2. hollow point with jacket chemically or mechanically bonded to core to prevent separation,
3. expansion valve with a wedge or ball forcing the bullet to expand on impact (The valve construction is used especially with solid copper alloy monobloc bullets).

Changing the tip of the bullet changes its aerodynamic form factor possibly reducing the ballistic coefficient C_b and shortening the tactical range. Upon impact these bullets start expanding at the tip. This makes the cross-sectional area larger and increases E_d . It will also shift the centre of gravity of the penetrating bullet closer to the tip making a long bullet in theory more stable in penetration. The dimensions and surface angles of the cavity together with the bullet materials and construction determine the rate and type of expansion.

SOFT TISSUE INJURY

As a projectile begins to penetrate tissue the retarding force of the tissue causes it to decelerate and lose kinetic energy. A penetrating bullet causes crushing, laceration, stretching and contusion of the tissue in the front and around it. The entrance wound is not necessarily very large as the impacting bullet is still undeformed and stable. The bullet induced pressure creates a temporary cavity first discovered by Woodruff [1898]. The pressure will rapidly accelerate and stretch tissues radially up to and beyond their breaking point until arrested by the elastic strength of the tissue.

During penetration the bullet may lose its stability and start tumbling. A deforming bullet, however, will change its form and thus its centre of gravity during penetration.

The penetration behaviour depends on the bullet's construction and on the retardation force it encounters. All these events make the bullet to present an increased cross-sectional area towards the penetration axis and thus transfer more of its kinetic energy into the tissue. The portion of the total kinetic energy that is transferred into tissue depends on how the bullet behaves during penetration, whether it tumbles, deforms or fragments and what the tissue induced retardation force is. The theory of Martel explains this phenomena and says:

$$E_d = C_v * V \quad (3)$$

where C_v is a constant depending on the prop-

erties of the target material and V the volume of the ensuing hole. Therefore the size of the inflicted area is directly proportional to the dissipated energy E_d .

SIMULATING BULLET INTERACTION USING LIVE AND NATURAL TISSUES

Wound ballistic simulation can be defined as the means to examine the injurious effects of a fire-arm launched projectile and to use the results for optimising its terminal performance. It is obvious that the effects of ammunition on human beings cannot be tested in vivo and credible simulations must be used. Even when extensive computer simulations are available and allow the shooting mathematical models of bullets into mathematical models of targets real bullets must eventually be used with real guns.

Overview of the tissue simulants

The most used tissue simulants:

1. Live, anesthetised animals - an animal model enables the study of physiological parameters and responses to the trauma. The pig is the most widely used of all animals. The non-homogeneity of living tissue causes dispersion of the results. A large number of repetitions may be required to gain sufficient statistical confidence.
2. Humans - military armed conflicts and civilian shooting incidents provide a wealth of information on firearms injuries. Human patients and cadavers could provide useful data for the development and validation of simulation methods.
3. Natural vital organs - natural vital organs of both humans and animals have been used for ballistic studies when cast into gelatine. These organs will provide useful information. Due to their structural complexity it is difficult to see how they could be replaced with synthetic simulants.
4. Synthetic simulants - simulants can be divided into soft tissue, skin, bone and skull simulants. Literature tends to concentrate on soft tissue simulants.

Soft tissue simulants

Principally two types of tissue simulants have been used: glycerine soap and the ballistic gelatine. There are also other attempts to use water, wet phone books, wet paper, clay, duct seal, transparent gel candle and even metallic lead.

Ballistic gelatine is usually used in 10 or 20 % nominal concentrations. The actual concentration should be adjusted i.e. calibrated for every batch of gelatine powder. The gelatine blocks are then taken to fridge for storage and cooling into prescribed usage temperature. Before use the gelatine block properties are verified by shooting 4.5 mm steel pellets into them and measuring both impact velocity (v_i) and penetration depth (l_w). An accepted de facto standard [Fackler and Malinowski 1988] is that at $v_i = 180$ m/s the l_w should be 85 ± 5 mm.

The first one to use gelatine as ballistic simulant was Harvey. He used 20% concentration at 24°C. The classic and often referred recipe

for gelatine is that of Fackler and Malinowski [1985]. They recommend using 10% solution for example 1000 g of gelatine with 9 l of water.

ANATOMY OF A BULLET WOUND

One of the tools used to compare the effects of ammunition is the “wound profile.” Wound profiles are simply dimensioned photos or carefully prepared scale drawings of test firings in calibrated ballistic gelatin. The wound profiles below are some typical examples of what a bullet does on impact. More work with wound profiles has been done with handgun ammunition than with rifle ammunition used for hunting. Properly prepared and calibrated ballistic gelatin gives performance and penetration results within about 2 percent of results obtained in actual tissue. “Properly prepared” means that the gelatin is a 10 % mixture of ballistic gelatin prepared water heated to no more than 40° C and then stored and shot at a stabilized 4 °C.

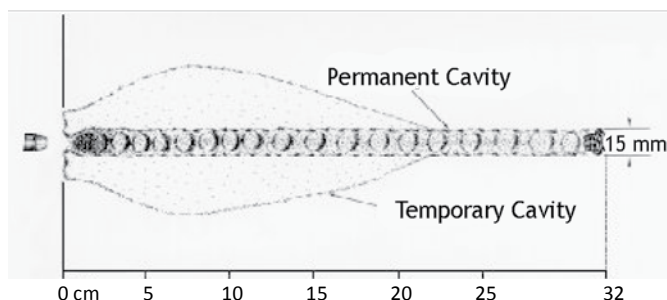


Fig. 1: Typical non-fragmenting expanding bullet wound profile produced by an expanding bullet

This particular profile is that of a 9.65 mm SPL +P 158gr. lead semi-wadcutter hollow point “FBI” load at 268.2 m/s. This particular load shows good penetration at 32 cm and good expansion at 1.5 cm. The Winchester Black Talon 9 mm 147gr JHP at 300 m/s produced an almost identical profile with penetration of 35 cm and expansion of 1.55 cm.

The shape and size of the temporary and permanent cavities are very similar to the 9.65 mm round above and penetration is only about

3.8 cm greater. Expansion is 1.68 cm, only 0.17 cm greater than the 9.65 mm round in spite of the vastly increased velocity. An excellent example of good bullet construction at work. The equivalent JHP round gives about 10 percent less penetration and a 1.78 cm expansion.

This profile is the M855 5.56 mm NATO cartridge, with a 62 gr. steel core FMJ (full metal jacketed) boat tailed bullet at 925 m/s. Penetration is acceptable at 34 cm. Note the long narrow neck of about 9 cm before the bullet

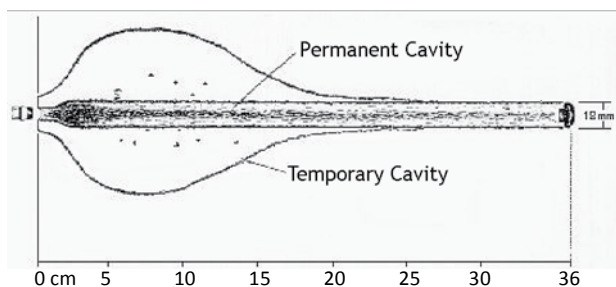


Fig. 2: Wound profile of Remington 125gr JSP 9 mm Magnum at 423.5 m/s

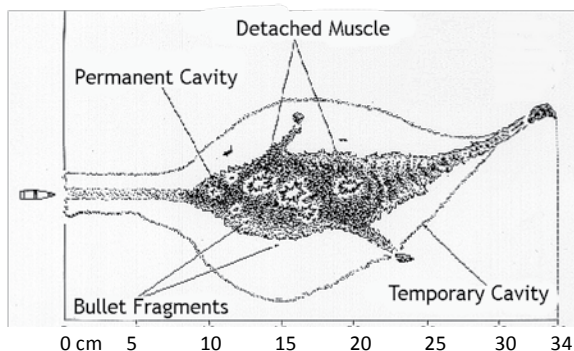


Fig. 3: Classic fragmenting rifle bullet profile

tumbles and fragments. These bullets fracture at the cannelure at velocities above about 823 m/s.

CONCLUSION

The paper proposes that 10% gelatine be used as a standard tissue simulant. It also studies effects of the mechanical properties of the human

tissue relevant to projectile penetration on the base of wound profile. The correlation between kinetic energy dissipation of a penetrating bullet and the tissue devitalisation it causes are described.

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SPECIAL PROBLEMS IN THE ANALYSIS OF CONTACT OF REAL BODIES

J. Menčík, L. Beneš

Abstract

The paper gives a brief overview of important factors in contact of real bodies. It starts with formulae for elastic contact, discusses two limit states (plastic flow and fracture) and explains the influence of tangential forces and origin of fatigue in rolling contact. It discusses the influence of surface roughness and situation in dynamic loading including stress waves and heat generation, and explains the solution for the contact of bodies from viscoelastic materials.

Key words

contact mechanics, stresses, deformations, fracture, stress waves

Load transmitting contact appears very often, and can become a source of wear or failure. The role is played by many factors, such as contact geometry, character of mutual movement of contacting bodies, time course and duration of contact, and mechanical properties of bodies in contact. The paper gives a brief overview of the main factors and shows when some of these phenomena should be considered or may be neglected.

BASIC FEATURES – ELASTIC DEFORMATIONS, STRESSES, ENERGIES

The contact force is usually transmitted over a small area, and the contacting surfaces here may be approximated by spheres, cylinders or ellipsoids. Under lower loads, the deformations are elastic. Basic idea can be obtained from the normal contact of spheres. In this case, the contact area is a circle, and the contact pressure is distributed parabolically with maximum value in the centre

$$p_0 = 1.5 p_m = 1.5 F / (\pi a^2) = \pi^{-1} (6 P E_e^2 / R_e^2)^{1/3} ; \quad (1)$$

p_m is the average contact pressure, a is the radius of contact area, and E_e , R_e are equivalent modulus and radius, obtained as the sum of material compliances and sum of curvatures of both bodies:

$$1/E_e = (1 - \nu_1^2)/E_1 + (1 - \nu_2^2)/E_2, \quad 1/R_e = 1/R_1 + 1/R_2; \quad (2)$$

E_1, E_2 are elastic moduli, ν_1, ν_2 are Poisson's numbers, and R_1, R_2 are radii of curvature of contacting surfaces. The displacement (approaching) of both bodies grows with the force nonlinearly as where

$$y = [9 F^2 / (16 R_e E_e^2)]^{1/3} = C F^{2/3}, \quad (3)$$

C is the contact compliance. Formulae for other shapes of contacting bodies can be found in literature, e.g. [1]. In all cases where the contact area increases with load, the relationships between load and displacement or contact pressure are nonlinear.

The stresses in contact area act in three directions. Their components can be expressed as a function of the characteristic contact pressure p_0 . The compressive stresses in the normal direction decrease continuously from surface into depth. Besides them, radial stresses act here, which are compressive near the surface, decrease with depth, at a small depth they change into tensile (!), attain a very low maximum and decrease to zero. Also shear stresses act in the contact area, with maximum value (approximately) $\tau_{\max} = 0.31 p_0$ at depth $a/2$ for spherical contact. On the surface, radial tensile stress also acts on the circumference of the contact area, of magnitude $\sigma_{r, \max} = p_0(1 - 2\nu)/3$.

During loading, contact force performs work equal the area below the $F(y)$ curve,

$$W = \int F dy = (2/5) C F^{5/3} = (2/5) F y. \quad (4)$$

The first part of this expression is general, while the other parts are valid for elastic contact of spheres. For other shapes, the constant C has different value. The work W changes into the strain energy, accumulated in the body temporarily if all deformations were only elastic. If also irreversible processes occur (e.g. plastic deformations or fracture), a part of the work is consumed by them.

LIMIT STATES – PLASTIC FLOW AND FRACTURE

The stresses $\sigma_{r, \max}$ and $\tau_{\max}$ are, together with the material properties and size of contact area, decisive for the failure mode. In ductile materials, plastic deforming starts as soon as the shear stress beneath the contact surface attains the shear strength of the material, which is approximately half of the yield stress σ_y in uniaxial compression or tension. Initially, the plasticised volume is very small and fully surrounded by elastically deformed material, and the load-displacement curve is nearly the same as for elastic deformations. Gradually, the plastic volume becomes larger, the deformations grow faster, and the $F(y)$ curve departs from that given by Eq. (3). Since some instant the plasticised material surrounds the contact area and the plastic flow becomes fully developed. In such case (e.g.

in hardness measurement by Vickers indenter), the mean contact pressure p_m is related to the yield stress (approximately) as $p_m = 3\sigma_y$. The energy consumed for plastic deforming can be much higher than the energy of elastic strains.

After unloading, residual stresses remain permanently in the material, compressive in the surface layer and small tensile below. In special cases with extensive plastic deformations during loading, the spring-back of the elastically strained material around the imprint can even cause reverse plastic flow in a small volume beneath the surface.

Brittle materials, such as glass and ceramics, are characteristic by very high theoretical strength and much lower tensile strength of common objects. Low strength is caused by the presence of numerous very small material defects, e.g. surface flaws in glass, which act as

stress concentrators. If such flaw is present at or near the edge of contact area, tensile stresses here can cause its growth, and a circular (and later conical) crack is formed here, especially if the contact circle has a diameter of several mm or more. For smaller radii of contacting bodies, the contact area is smaller, so that the probability of occurrence of a larger or suitably oriented surface flaw here decreases, and the force, necessary to cause its growth, must be higher. As a consequence, all contact stresses are higher, including the shear stresses below the surface. So it can happen that the material begins to deform plastically here before a larger crack at the circumference of contact area could be formed. Evidence for this are permanent imprints of microscopic size (without a crack), created by a diamond pyramid under low load. For higher loads, larger extent of plastic flow in brittle material nucleates a crack at some depth below surface, which extends soon to the surface. The formation of cracks is enhanced by the shape of contacting bodies. If the contact surface has shape of a long ellipsoid or an edge, tensile force acting beneath the surface perpendicularly to the long axis is higher and promotes the crack nucleation and propagation.

TANGENTIAL FORCES AND SHEAR STRESSES

Tangential force T causes shear stresses, which are maximum on the contact surface and decrease with depth. Also normal stresses appear in the direction of the force T , which are compressive in front of the contact area and tensile behind it. Usually, tangential force T acts simultaneously with the normal force F , related to it as $T = \mu F$, where μ is the coefficient of friction. The corresponding stress components are superimposed. The resultant shear stress is slightly higher, and its maximum is nearer to the surface, more for higher values of μ . Significantly larger is the increase of tensile stresses (parallel to the surface) acting at the rear edge of contact area, and this can be dangerous especially for brittle materials.

FATIGUE IN ROLLING CONTACT

In contact, the shear stress caused by the load perpendicular to the surface attains the maximum at the axis of symmetry (z) in two planes inclined to it by 45° . Outside the z axis, the shear stresses act in the planes and directions parallel to the contact surface. They act leftwards at the left side from the z -axis, and rightwards at the right-hand side. If the position of contact changes, for example in mutual rolling, the sign of shear stresses at certain point changes also. Repeated contact in rolling thus causes alternating shear deformations and stresses, which can lead to initiation of a fatigue crack below the surface. This crack can gradually grow and when it arrives the surface, a small material particle splits off (pitting fatigue, common for ball bearings and other rolling parts).

INFLUENCE OF SURFACE ROUGHNESS

No surface of real bodies is perfectly smooth. Due to manufacturing technologies it often contains various asperities, grooves, depressions and heights. This shape can be described by analytical expressions corresponding to the particular manufacturing technology (e.g. grinding), and containing also a component characterising random variations.

As a consequence of surface roughness, two real bodies come into first contact only at local peaks. The actual area of contacting surfaces is smaller than the „macro“ contact area, and also the radii of curvature of these heights are smaller. As a consequence, the local contact pressure and stresses at these asperities are higher than for the ideal surface under the same force. The asperities deform faster, and both bodies approach mutually faster as if they had a microscopically thin softer layer on the surface. Gradually, effective curvatures of the heights in contact become smaller and approach to the macrocurvature of the ideal surfaces in contact. This is facilitated by local plastic flow.

The surface roughness must be considered in any contact analysis if the height of asperities is not negligible compared to the total contact

deformation calculated under assumption of ideal surfaces. It is especially important in the study of friction, wear and other kinds of surface damaging.

HEAT GENERATION IN CONTACT

The irreversible work (e.g. due to plastic deforming) can be determined as the difference between the $F(y)$ curves for loading and unloading. This work changes into heat, which can be important if the heat generation (during fast loading or under repeated loading) is faster than its conduction away from the contact area, so that the temperature here can significantly increase. In some cases it results in changes in material structure and properties.

Another source of heat is the friction in sliding contact. The dissipated power P is obtained as

$$P = Tv = F f v \quad (5)$$

where T is the tangential (friction) force, F is the normal force, f is the coefficient of friction and v is the velocity of mutual sliding. Again, relatively high power P causes increase of temperature, which can lead to the changes in the material, and sometimes even to its melting.

There is one more aspect of this process. The heat is generated at some surface point only as long as the friction contact here exists. Simultaneously, the heat is conducted into the body and (partly) into the surrounding medium, e.g. air. If the heat generation was very intensive and lasted very short time, only a thin surface layer was influenced. In such case, high temperature and a high temperature gradient can arise here. This leads to the fast decrease of temperature after the contact (e.g. by conduction into the cooler interior of the body [2]), which can again cause changes in the material, like in quenching.

DYNAMIC LOADING AND WAVE EFFECTS

Normal contact

Mechanical impulses propagate through a solid body by the velocity of sound in the pertinent material. There are various kinds of waves (longitudinal, transversal, Rayleigh waves, propagating along the surface, etc.). The first idea about their influence can be obtained from longitudinal waves propagating in one direction, e.g. in a long thin bar. Their velocity is $c = \sqrt{E/\rho}$, where E is elastic modulus and ρ is the material density. In more complex cases, also Poisson's ratio plays a role. If a massive rigid body hits an elastic bar in axial direction by the velocity v , stress wave of magnitude

$$\sigma = E v / c$$

starts propagating immediately along the bar. After reaching its opposite end, it is reflected and propagates back to the contact surface. If the striking body is still in contact and continues moving, the stress wave again reflects at the contact surface and propagates towards the fixed end, etc.

A rough idea about the significance of wave effects can be obtained from Eq. (6), despite of it being only for onedimensional case. With respect to the high velocity c of sound, these effects usually play a role for impact or contact velocities tens or hundreds m/s. For example, the velocity of sound in steel is about 5200 m/s. Then, if the velocity of impact is 5 m/s, the corresponding wave stress is $\sigma = (5/5200)E = 0.001 E$, which is about 200 MPa. For $v = 50$ m/s, the dynamic stress would be about 2000 MPa. For contact velocities below 1 m/s the wave effects may usually be neglected, and the contact can be analysed using static formulae. This also holds for impact.

Stress waves in rolling contact

Stress waves can also play a role in fast rolling contact. In any contact, the normal force pushes the material inwards, i.e. perpendicularly to the surface. If one body (e.g. a wheel) rolls by a high velocity along the surface of another body, the position of contact changes. If the contact surface makes a part of a sphere or a cylinder, the fastest movement of the material inwards is

at the edge of contact area. If the angle of the slope of contact surface here is α , the normal velocity is $v = u \tan \alpha$, where u is the velocity of the moving body along the surface. For equivalent contact radius R and half-width of contact area a ($\ll R$), the angle α is very small, so that $\tan \alpha \approx \sin \alpha = a/R$, and the possible effect of wave stresses can be assessed by inserting $v = u a/R$ into Eq. (5), where the half-width of contact area is estimated from static solution for the load F . If these effects are not negligible (e.g., fast trains go by velocities 100 m/s or higher), more accurate dynamic analysis must be done.

Stresses in quasistatic impact

For lower velocities with negligible wave effects, maximum stresses can be obtained via the law of energy conservation. Kinetic energy of the impacting body is gradually converted into the strain energy, and this conversion is complete when the velocity of moving bodies became zero. The impact energy changes fully into the energy of elastic stresses if the deformations during the contact were only elastic. If also plastic deformations have occurred, a part of the energy was spent for them. Energy is also spent if some cracks or fracture surfaces were created. Generally, the work W of contact stresses corresponds to the area below the force–displacement $F(y)$ curve (cf. the integral in Eq. 4). Vice versa, if the energy of impact is known, the knowledge of the $F(y)$ curve makes possible the determination of maximum force F and impact stresses.

CONTACT OF BODIES FROM VISCOELASTIC MATERIALS

Deformations of polymeric materials depend not only on the load magnitude, but also on its duration and time course. Typical features are slow increase of deformations under constant load or stress relaxation under constant deformation. The load response of these materials is usually modelled by springs and dashpots and described by creep compliance function $J(t)$, for example $J(t) = C_0 + C_1[1 - \exp(-t/\tau_1)]$ for Standard Linear Solid (spring in series with another spring connected in parallel with a dashpot). C_0

and C_1 are compliance constants, and τ_1 is so-called retardation time. For contact problems it is possible to use the elastic solution for the same geometry, with the elastic constants replaced by a viscoelastic integral operator. The relationship between displacement and load under monotonic loading can be expressed generally as

$$f[y(t)] = K \psi(F, J, t), \quad (7)$$

where f is some function of the displacement y , K is a constant characterising the contact geometry, and $\psi(F, J, t)$ is a function depending on material parameters (J), load magnitude (F) and history; t is time. For spherical contact, $f = h^{3/2}$ and $K = 3/(4\sqrt{R})$. For ideally elastic materials, $\psi = 2F(1 - v^2)/E_e$. The corresponding general formula for linearly viscoelastic materials is

$$\psi(t) = \int J(t-u) [dF/du] du, \quad (8)$$

where u is a dummy variable for integration (performed from 0 to t). More details can be found in [1].

The situation is much simpler if only reversible viscoelastic deformations appear. Then, elastic solution for two limit cases is sufficient. One corresponds to very fast loading, and is obtained for the elastic compliance C_0 (= reciprocal of the “fast” elastic modulus). The second case corresponds to very long time under load, and the deformations are obtained by elastic solution for the sum of all compliances (e.g. $C_0 + C_1$). The deformations gradually increase from one limit case to the other, their velocity being characterised by the time constants. After unloading, the deformations gradually vanish.

ACKNOWLEDGMENT

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VERTICAL DIFFERENTIAL COMPONENT OF THE TEMPERATURE LOAD EVALUATED FROM THE LONG-TERM EXPERIMENT CARRIED OUT ON THE PRESTRESSED CONCRETE BRIDGE

M. Polák, T. Plachý

Abstract

This paper describes the vertical differential component evaluation procedure of the temperature load from the results of a long-term experiment, in which the temperature changes in cross-section plane of the prestressed concrete box-girder bridge are systematically observed. The regression plane was smoothed through the measured temperature data in each observed point of the bridge cross-section using the regression analysis at every time instant of the performed measurement. The results of the evaluation are compared with limit values prescribed in standard [1].

Key words

long term experiment, temperature load, prestressed concrete bridge

Many important building structures are permanently exposed to the climatic changes of air temperature, changes of insolation of their surfaces during days and year periods. These

changes cause time variable courses of temperature in individual components, cross-sections and points of these structures. Temperature change causes deformation of a structure. If we

restrain these deformations, then an additional strain – temperature load arises in the structure. In accordance with Czech standard ČSN EN 1991-1-5 we can divide the temperature course in four basic components of temperature in a certain cross-section: uniform component of temperature ΔT_u , linearly changing difference component of temperature in the vertical direction ΔT_{My} , linearly changing difference component of temperature in the horizontal direction ΔT_{Mz} , non linear difference component of temperature ΔT_E .

This article describes the procedure used for evaluation of vertical differential components of the temperature load from the data collected during a long-term experiment – observation of temperature changes - in the cross-section plane of the prestressed concrete box-girder bridge. The regression plane was smoothed through the measured temperature data in each observed point of the bridge cross-section using the regression analysis at every time instant of the performed measurement. The results of the evaluation are compared with limit values prescribed in standard [1].

DESCRIPTION OF THE PERFORMED EXPERIMENT

The experiment was performed on the box-girder bridge at the 63th km of motorway D1 over Želivka reservoir. The experiment is performed

on the outside box-girder of the bridge used for the traffic from Brno to Prague. The supporting structure consists of a 3-span frame (54 m, 75 m a 54 m) made from prestressed concrete. The supporting structure of this bridge was assembled of two rows of box type segments of a constant height 4.20 m and width of the upper slab 6.0 m (Fig. 1) which were mutually connected. The total width of supporting structure is thus 13.0 m.

A measuring line, which permanently monitors temperature changes, is installed on the bridge. The measuring line consists of the measuring device MS2+ from the firm Comet System and of the 16 temperature sensors of type N1ATG7/0. All sensors are placed in a single cross-section of the box in the middle of the central span (see Fig. 1). For the purpose of calculating basic components of temperature, the sensors are placed in pairs in slabs and sidewalls. For the sensors No. 1, 3, 5, 7, 11 and 13 openings were drilled from the inside of the supporting structure to place the sensors approximately 2–3 cm from an external surface of the supporting structure. The sensors No. 2, 4, 6, 8, 12 and 14 are attached at the inner surface of the box. The air temperature is measured in the box (the sensor No. 9) and outside of the structure (the sensor No. 10). The temperature in the observed points is scanned every 15 minutes by trouble free activity of the measuring device.

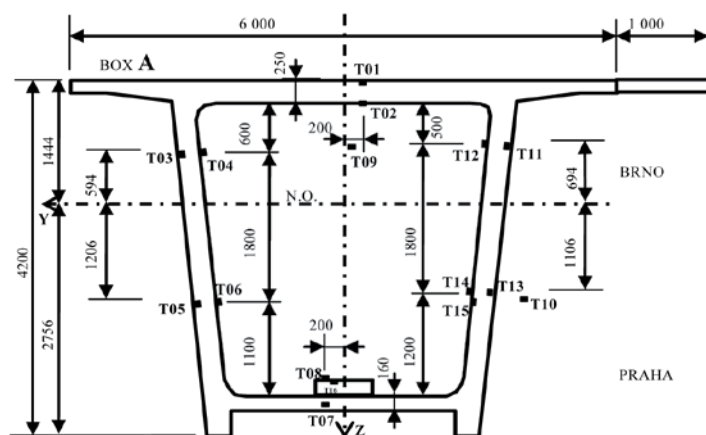


Fig. 1: Positions of the temperature sensors in the observed cross-section of the box A

THE EVALUATION OF BASIC COMPONENTS OF TEMPERATURE LOAD

By evaluation of basic components of temperature load (ΔT_u , ΔT_{My} , ΔT_{Mz}) of the monitored cross-section of the prestressed concrete bridge, the measured values were processed using the regression analysis. An approximation plane described by equation

$$T(y_i, z_i, t) = \Delta T_u(t) + K_y(t)y + K_z(t)z \quad (1)$$

was interlaid through the measured values of temperature $T(y_i, z_i, t)$ in individual points of the cross-section at each time instant t of the measurement, where y_i and z_i are the horizontal and vertical coordinates of the point in which the temperature was measured, $K_y(t)$ is the slope of a straight plane approximation in horizontal direction and $K_z(t)$ is the slope of a straight plane approximation in vertical direction corresponding to the time of measurement t . For the estimate of the parameters of the regression plane, the Least Square Method was used, which in this case leads to solving a system of three equations of three unknowns $\Delta T_u(t)$, $K_y(t)$ and $K_z(t)$. The nonlinear difference component of temperature $\Delta T_E(y_i, z_i, t)$ was determined in the individual points of the box based on relation

$$\Delta T_E(y_i, z_i, t) = T(y_i, z_i, t) - (\Delta T_u(t) + K_y(t)y + K_z(t)z) \quad (2)$$

	ΔT_u		ΔT_{My}		ΔT_{Mz}	
	$T_{e, \min}$ [°C]	$T_{e, \max}$ [°C]	$\Delta T_{My, \text{heat}}$ [°C]	$\Delta T_{My, \text{cool}}$ [°C]	$\Delta T_{Mz, \min}$ [°C]	$\Delta T_{Mz, \max}$ [°C]
Experiment 2006	-10.3	29.3	-5.1	3.3	-2.2	2.2
Experiment 2007	-3.7	29.2	-5.1	2.9	-1.7	2.6
Standard [1]	-24	40	-10	5	-5	5

Tab. 1: The extreme values of the basic components of temperature loads ΔT_u , ΔT_{My} , ΔT_{Mz} of years 2006 and 2007 (the evaluation procedure with the regression plane smoothing through temperature data)

	ΔT_E in T01		ΔT_E in T02		ΔT_E in T07	
	$\Delta T_{E, \max}$ [°C]	$\Delta T_{E, \min}$ [°C]	$\Delta T_{E, \max}$ [°C]	$\Delta T_{E, \min}$ [°C]	$\Delta T_{E, \max}$ [°C]	$\Delta T_{E, \min}$ [°C]
Experiment 2006	5.9	-2.5	2.7	-1.6	1.9	-1.2
Experiment 2007	6.0	-1.9	2.7	-1.7	1.8	-1.4

Tab. 2: The extreme values of the nonlinear difference component of temperature loads ΔT_E of years 2006 and 2007 in points T01, T02 and T07 (the evaluation procedure with the regression plane smoothing through temperature data)

	ΔT_u		ΔT_{my}	
	$\Delta T_{e, \min}$ [°C]	$\Delta T_{e, \max}$ [°C]	$\Delta T_{M, \text{heat}}$ [°C]	$\Delta T_{M, \text{cool}}$ [°C]
Experiment 2006	-10.3	29.2	-5.1	3.3
Experiment 2007	-3.7	29.2	-5.2	2.9

Tab. 3: The extreme values of the basic components of temperature loads ΔT_u , ΔT_{My} of years 2006 and 2007 (the evaluation procedure with the vertical regression line smoothing through temperature data)

	ΔT_E in T01		ΔT_E in T02		ΔT_E in T07	
	$\Delta T_{E, \text{heat}}$ [°C]	$\Delta T_{E, \text{cool}}$ [°C]	$\Delta T_{E, \text{heat}}$ [°C]	$\Delta T_{E, \text{cool}}$ [°C]	$\Delta T_{E, \text{heat}}$ [°C]	$\Delta T_{E, \text{cool}}$ [°C]
Experiment 2006	5.9	-2.5	2.7	-1.6	1.9	-1.2
Experiment 2007	6.0	-1.9	2.7	-1.7	1.8	-1.4

Tab. 4: The extreme values of the nonlinear difference component of temperature loads ΔT_E of years 2006 and 2007 in points T01, T02 and T07 (the evaluation procedure with the vertical regression line smoothing through temperature data)

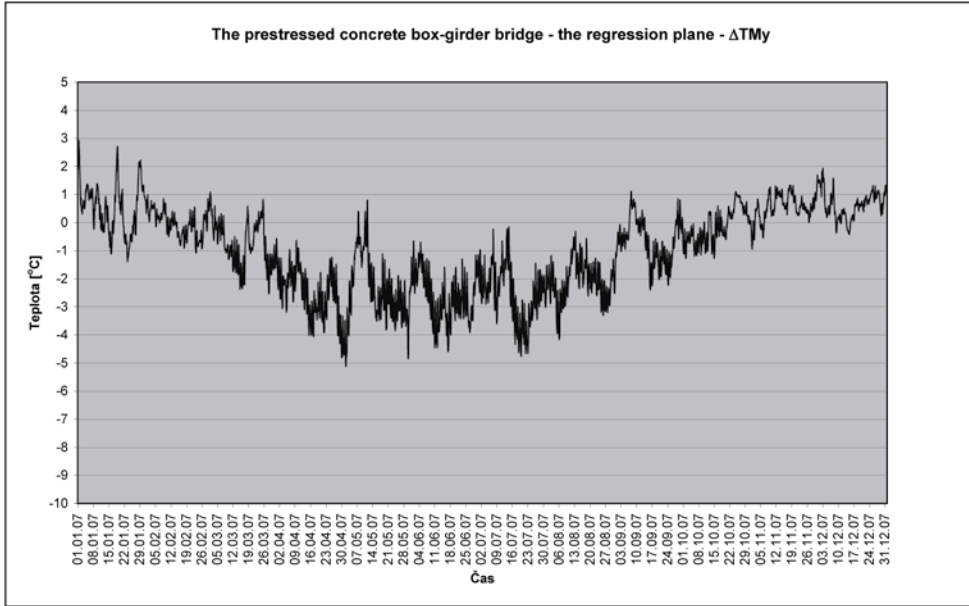


Fig. 2: Course of a linearly changing difference component of temperature in the vertical direction ΔT_{My} on the observed bridge during the year 2007

CONCLUSION

The courses of the uniform component of temperature ΔT_u , the linearly changing difference component of temperature in the vertical direction ΔT_{My} (Fig. 2), the linearly changing difference component of temperature in the horizontal direction ΔT_{Mz} and the nonlinear difference component of temperature ΔT_E were evaluated by procedure with the regression plane smoothing through temperature data measured on the observed prestressed concrete box-girder bridge during the years 2006 and 2007.

Evaluated extreme values of basic components of thermal action and their comparison with corresponding values prescribed in the standard [1] are listed in Tab. 1, were $T_{e, \text{max}}$, $T_{e, \text{min}}$ are the maximal and the minimal uniform com-

ponents of temperature of the bridge, $\Delta T_{My, \text{heat}}$ (Fig. 3) corresponds to the stage of the bridge, when the upper surface is warmer than the bottom surface and by $\Delta T_{My, \text{cool}}$ (Fig. 4) the upper surface is colder than the bottom surface, $\Delta T_{Mz, \text{min}}$ corresponds to the stage of the bridge, when the surface of the inner sidewall is warmer than the external sidewall surface and by $\Delta T_{Mz, \text{max}}$ the surface of external sidewall is colder than the inner sidewall surface. The evaluated extreme values of the nonlinear difference component of temperature loads ΔT_E of years 2006 and 2007 in the selected points are presented in Tab. 2.

The evaluation procedure with the vertical regression line smoothing through temperature data measured on the observed bridge is

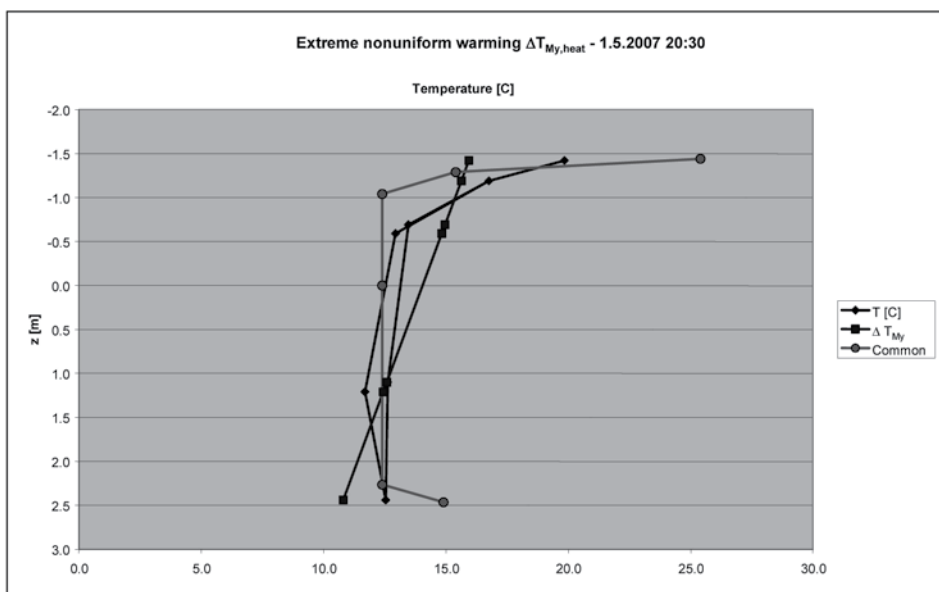


Fig. 3: Extreme difference component of temperature $\Delta T_{My,heat} = -5.2$ °C - year 2007

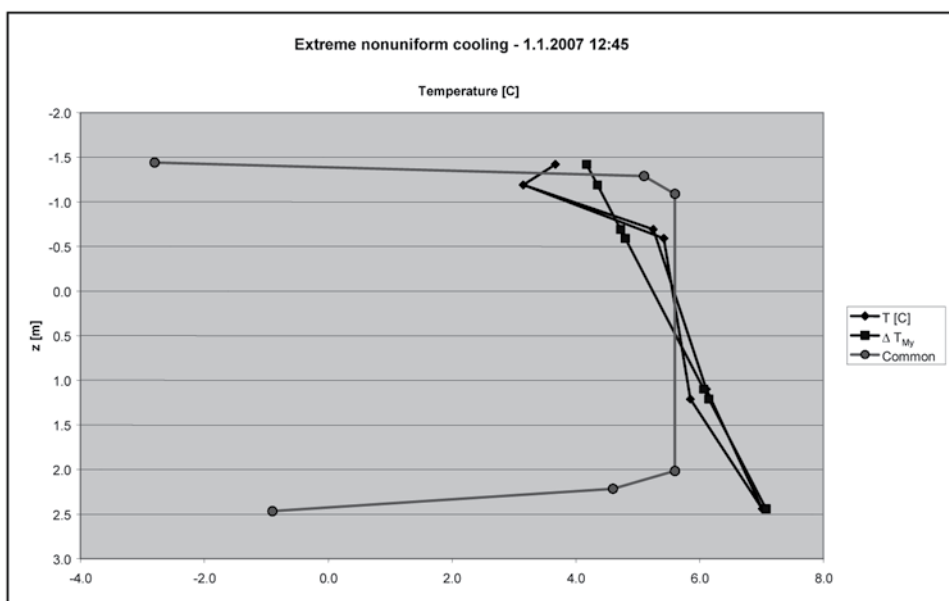


Fig. 4: Extreme difference component of temperature $\Delta T_{My,cool} = +2.9$ °C - year 2007

described in the paper [2]. The ΔT_{Mz} is impossible to evaluate by this technique. But when the evaluated extreme values of ΔT_u , ΔT_{My} and ΔT_E (see Tab. 3 and 4) are compared with the values determined using the regression plane smoothing (see Tab. 1 and 2), the differences are small and not exceed the limit 0.1 °C. From the listed

results, it is clear that the values prescribed in the standard ČSN EN 1991-1-5 [1] were not exceeded in the years 2006 and 2007.

This research has been supported by Czech Ministry of Education, Youth and Sports, under project No. MSM 6840770031.

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OPTIMAL DIAGNOSTIC MODEL OF ROTATING MACHINES

R. Antunovic

Abstract

The advances in computer technology have brought tremendous improvements in increasing accuracy, as well as in reducing time and effort consumed by data acquisition and processing. The improvements are also in the volume and speed of performed operations, from the beginning of data collection, to the final display of the data now available in cross-correlated formats. Decreasing costs of computerized data acquisition/processing systems, and their efficiency, result in increasing cost-effectiveness of their application in industry maintenance problems. Vibration measurement and analysis have acquired special significance, because they provide a large amount of quality information with a low capital investment. The choice of minimal combination of diagnostics formats which are going to give an optimale opportunity of detection dynamical problems is made, with complete effecton of use end simplicity in using.

Key words

rotation machines, vibrodiagnostics, analyzers models, optimization

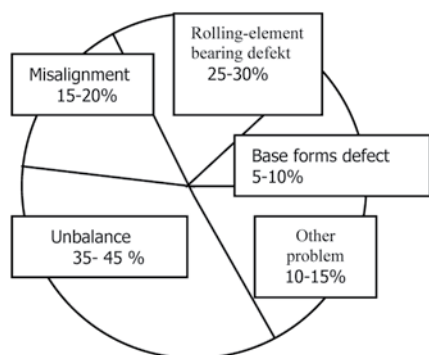
Vibration measurement and analysis have acquired special significance, because they provide a large amount of quality information with a low capital investment. Existing vibro-diagnostics methods which are development on existing analyzers vibration of leading world companies, are researched end quality. Which method to choose in an individual case is determined not only by the construction of the machines to be investigated, but is mainly dependent on the expenditure commitment and the depth to which machine diagnosis will be utilized.

The function of set aim in this particular case is the selection of optimal set of formats of vibrodiagnostics that provide the maximal possibility of detection, selection and verification of dynamic problem, considering economic rationality and simplicity for use. Beside the researches that were performed, the literature of leading world companies from this field of work is used. Here are some of them: Bruel & Kjaer, Vibro; SCHENCK; Bently Nevada; SKF; SPM etc.

OPTIMAL OF VIBRODIAGNOSTICS MODEL

During research, we came to conclusion that optimal model could be seen when using four valuable functions [1]:

1. Identifying the cause of dynamic problem
2. Simplicity for use and performance



3. Early detection cause of dynamic problem
4. Economic aspect

Dynamics problem in rotating machines

Dynamic problem is typical for certain group of machines, depending on their power, rotation, construction, base etc. Using standard ISO 10.816 all machines are classified in 4 classes and each class of machines has its recommended and allowed level of vibration, measuring points for vibration, the way of measurement and the selection of parameters for measurement. Analyzing certain causes of dynamic problems, we can conclude that the certain causes are typical for two types of machines:

- GROUP 1:
 - a. Machines classes I – in according ISO 10816
 - b. Machines classes II – in according ISO 10816

Characteristics of this group machines has own rolling-element bearings.

- GROUP 2:
 - a. Machines classes III - in according ISO 10816
 - b. Machines classes IV - in according ISO 10816

Characteristics of this group machines has own journal bearings.

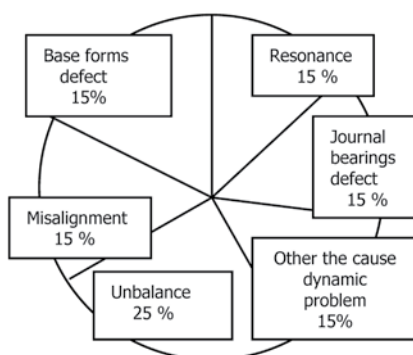


Fig. 1: Possibility of certain defect appearance in machines Group 1 and Group 2

Chosen set of vibrodiagnostics format

Vibrodiagnostics formats that are taken into consideration came from parallel analyses of appropriate equipment of leading world com-

panies in this area and also from our long term research and development. For this selection of specific set of formats we requested minimal number of vibrodiagnostics formats which could discover the existence of certain cause for dynamic problem in machine systems [3].

Set A (basic set which is a component of all other models)	Set B	Set C	Set D	Set E	Set F
1. Overall of vibrations 2. Frequency spectrum 3. Polar trend plot 4. Time picture of signals	1.HFD (High Frequency detection) values	1. SED (Selective Envelope Detection) analysis	1. Bode plot 2.Cascade spectrum plot	1. Smax 2.X-Y position 3.Orbit plot	1. System analysis

Tab. 1: Set of vibrodiagnostics format

Analyzers models

Models of analyzers are chosen independent for two machine groups. For comparing there are some analyzers leading words company.

Machines Group 1					
Type	Model I	Model II	Model III	Model IV	Model V
Composition of sets	A	A+B	A+B+C	A+B+C+E	A+B+C+E+G

Tab. 2: Chosen models analyzers for machines Group 1

Machines Group 2					
Type	Model I	Model VI	Model VII	Model VIII	Model IX
Composition of sets	A	A+D	A+D+E	A+D+E+F	A+C+D+E+F+G

Tab. 3: Chosen models analyzers for machines Group 2

Values of aim function

1. Identifying the cause of dynamic problem,
 2. Simplicity for use and performance,
 3. Early detection cause of dynamic problem,
 4. Economic aspect,

z = 0,5
 z = 0,2
 z = 0,2
 z = 0,1

Values of aim function =

$$\sum_{i=1}^4 z_i * V_i$$
(1)

where:

V_i – value of certain function, z_i – certain level of importance

Analyzers models	Values of aim function
Model I	78,75
Model II	84,00
Model III	82,65
Model IV	79,05
Model V	70,45

Tab. 4: Values of aim function for mach. Gr. 1

Analyzers models	Values of aim function
Model I	82,00
Model VI	80,85
Model VII	77,90
Model VIII	75,40
Model IX	68,42

Tab. 5: Values of aim function for r mach. Gr. 2

MEASUREMENT RESULTS

This is presented practically identifies the cause of dynamic problem that occurred in machines in real conditions of exploitation.

Diagnosis of EP

1. Thermal Power Plant Gacko
2. Plant: Pump
3. Data and time measurement:
25.06.2006 in 11:30
4. The results

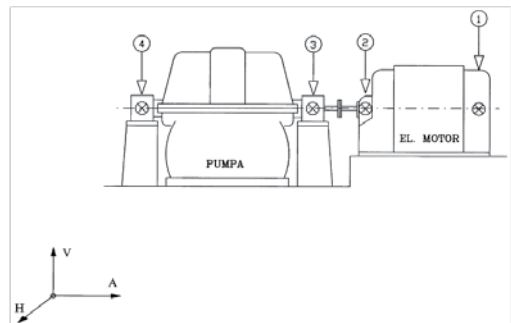


Fig. 2: Show plant pump

- Overall of vibrations

Bearings	Horizontal	Vertical	Axial
	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]
1	1,6	1,2	1,8
2	1,2	1,1	1,3
3	1,9	2,1	1,5
4	3,2	3,1	1,2

Tab. 6: Overall of vibrations in pump bearings

EVOLUTION MACHINES

Evolution from in ISO 10816 standard: permissible.

- Spectral analysis

Let's show spectral plot horizontal vibration in 4-th bearings.

Damage characteristic frequency for SKF6318: BPFO= 38,6 Hz; BPFI=61,2 Hz; BSF=26,1 Hz; FTF=4,75 Hz, frequencies hydraulic damage BPF=75 Hz, for RPM=1500.

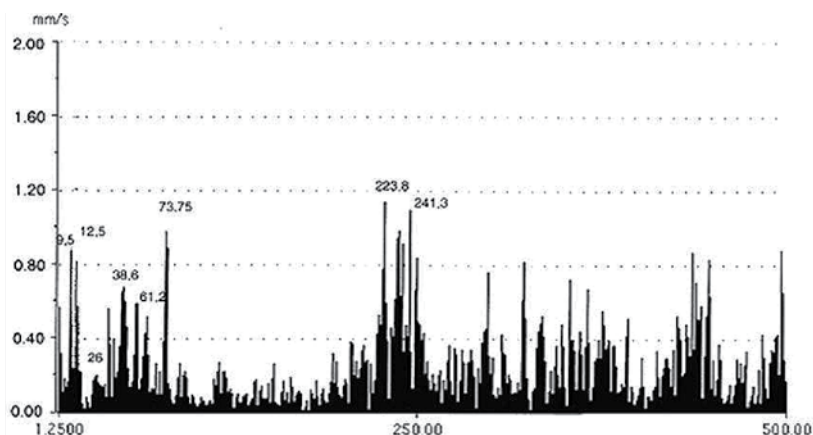


Fig. 3: Spectrum plot horizontal vibration for 4 bearings

This is spectrum plot which shows detection of damage in rolling-element 4-th bearings.

- HFD values

HFD values is 9,2 g. This is high values.

CONCLUSIONS

Final measurements and examinations have proven that chosen models of vibrodiagnostic unmistakably identify causes of dynamical

problems appearing on machines while being exploited, in rather fast and simple manner. Further optimization of each of chosen vibrodiagnostic formats could be done. Chosen optimal model of vibrodiagnostic may serve to:

- for adjusting currently developed and assembled diagnostic systems,
- specification and purchase of new diagnostic equipment,
- development of new structures of vibration analyzers.

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STATISTICAL VERIFICATION OF ZERO SHRINKAGE IN SINTERS BASED ON HYDROXYAPATITE WITH ADDITION OF ZIRCONIUM PHASE

A. Dudek, C. Kolan

Abstract

A wide range of advantages of implants which contain hydroxyapatite results from e.g. level of their porosity. There are also attempts to improve poor mechanical properties of HAp coatings through introduction of e.g. solid solution of Y_2O_3 in ZrO_2 [1-7].

This work encompasses compositions of ceramic powders based on HAp+ ZrO_2 with addition of 8%wt. Y_2O_3 and 20%wt. Y_2O_3 . The powders were axially compacted and then sintered at the temperature of 1300°C for two hours. After the process of sample sintering the geometrical measurements were taken in order to determine volume shrinkage in each sample.

For the obtained experimental points the linear regression equations were matched by means of least squares method and the correlation coefficient was calculated. For the obtained linear equations and the corresponding correlation coefficients, tests were performed at the significance level of $\alpha=0.05$.

Key words

biomaterials, hydroxyapatite, analysis of regression and correlation

According to the definition accepted by the European Society for Biomaterials, the biomaterials are substances which are not medicines or which are a combination of natural or synthetic substances being able to replace a part or the whole system [2].

The increased interest in biomaterials, which is connected with opportunities of use of them for implants, causes, on the one hand, continuous rise in requirements for such materials and on the other hand, searching for new methods

and technologies for improvement in their usable properties. Particularly significant application aspect of implants is their biotolerance inside human body while other important features include corrosion, wear and mechanical properties. Complementary properties of metallic and ceramic biomaterials is a good basis for composite-based implants design.

The composites which contain orthophosphates, particularly hydroxyapatite-based (HAp) ceramics, have highest importance in ceramic

biomaterials used to obtain e.g. coatings on the metallic implant surface. Hydroxyapatites (HAp, OHAp, HA) are the compounds which are present in human and animal bone systems.

Wide use of bioceramic HAp layer for medicine applications is justified by numerous advantages, such as: lack of cytotoxic or carcinogenic effects, high chemical purity, good adaptation to the body and beneficial chemical composition.

Due to short times of life and reliability of composite implants [8], resulting from lower level of their mechanical properties, the need arises for searching for methods of modification which would lead to elimination of the abovementioned problems. The most common changes in chemical composition of a protective composite created on the surface of implants consist in introduction of a solid solution of Y_2O_3 in ZrO_2 (YSZ) or TiO_2 into hydroxyapatite ceramic.

MATERIALS FOR INVESTIGATIONS

Hydroxyapatite powder of $Ca_{10}(PO_4)_6(OH)_2$ (with purity of 99 %wt. and $Ca/P = 1,67$) as well as ZrO_2 zirconium oxides modified with 8%wt. Y_2O_3 and 20% wt. Y_2O_3 (Sulzer Metco) (Fig. 1) were used for the investigations.

The purpose of the investigations was to obtain sinters on hydroxyapatite base with addition of variable contents of two zirconium powder ceramics modified with yttrium oxide.

After homogenization of mixtures of selected composition, the powders were axially compacted with load of 85 MPa and dried in laboratory drier. As a result of the performed operations, moulded pieces were obtained with the following nominal dimensions: $\phi=30$ mm, $h=5$ mm.

During further stage of the investigations the obtained moulded pieces were sintered at the temperature of $1300^\circ C$ for two hours.

After sintering process the samples were subject to geometrical measurements in order to determine volume shrinkage in each sample.

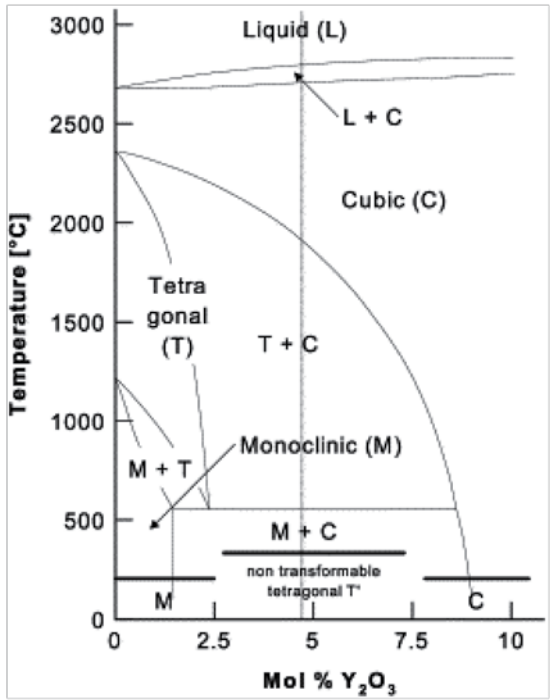


Fig. 1: Types of zirconium ceramics depending on contents of modifying phase of Y_2O_3 [1]

RESULTS

In order to formulate generalized dependencies between contents of zirconium phase and shrinkage in the obtained sinters the regression and correlation concepts were employed.

For the obtained experimental points linear regression equations were matched by means of least squares method and correlation coefficient was calculated. For the obtained linear equations and corresponding correlation coefficient the tests were made with the significance level of $\alpha=0.05$, and using the following dependencies:

- significance test for correlation coefficient
$$t = \frac{r}{\sqrt{1-r^2}} \sqrt{n-2} \quad (1)$$

where: n – number of degrees of freedom, r – correlation coefficient

- significance test for coefficients of simple regression equation
$$t = \frac{A-A_0}{S_r} \sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} ; S_r = \sqrt{\frac{1}{n-2} \sum_{i=1}^n (y_i - \hat{y})^2} ; t = \frac{B-B_0}{S_r} \sqrt{\frac{n \sum_{i=1}^n (x_i - \bar{x})^2}{\sum_{i=1}^n x_i^2}} \quad (2)$$

where: S_r – remaining deviation, A, A_0 – values direction component, B, B_0 – absolute term.

- confidence interval for direction component of simple regression

$$P \left[A - t_{\alpha} \frac{S_r}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2}} < A' < A + t_{\alpha} \frac{S_r}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2}} \right] = 1 - \alpha \quad (3)$$

where: t_{α} - value of T-Student statistics for $n-2$ degrees of freedom and the accepted confidence level $1-\alpha$.

- asymptotes equation for confidence corridor

$$\hat{y}_1 = B_1 + A_1 \quad \hat{y}_2 = B_2 + A_2 x \quad (4)$$

- confidence corridor for simple regression

$$P[\hat{y} - t_{\alpha} S_{\hat{y}_i} < \tilde{y} < \hat{y} + t_{\alpha} S_{\hat{y}_i}] = 1 - \alpha \quad S_{\hat{y}_i} = S_r \sqrt{\frac{1}{n} + \frac{(x_i - \bar{x})^2}{\sum_{i=1}^n (x_i - \bar{x})^2}} \quad (5)$$

The results of the performed calculations are presented in Fig. 2-3. These calculations show strong dependence between the contents of zirconium phase and samples shrinkage after sintering process. It is proved by high values of correlation coefficient $r^2 > 0.98$.

On the basis of regression curves one can determine the content of zirconium phase at which sinters on hydroxyapatite base will show zero shrinkage. In the case of HAP + (ZrO₂+8%wt. Y₂O₃) ceramics, a simple extrapolation method enabled determination of ZrO₂+8%wt. Y₂O₃ powder content which ensured zero shrinkage with amount of 70.6% wt. Content interval determined from confidence corridor amounts to from 65% to 76% wt.

Similar considerations were made for HAP + (ZrO₂+20 %wt. Y₂O₃) ceramics and enabled determination of zero sample shrinkage at addition of 76% wt. of ZrO₂+20 %wt. Y₂O₃ powder. Confidence corridor range for these samples was from 71% to 82% wt.

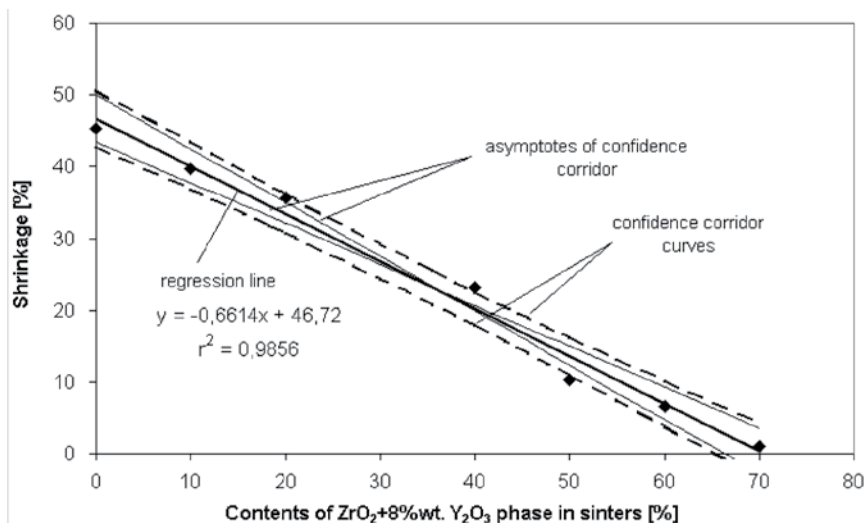


Fig. 2: Correlation chart with confidence corridor for HAp + (ZrO₂ + 8 wt. Y₂O₃) sinters

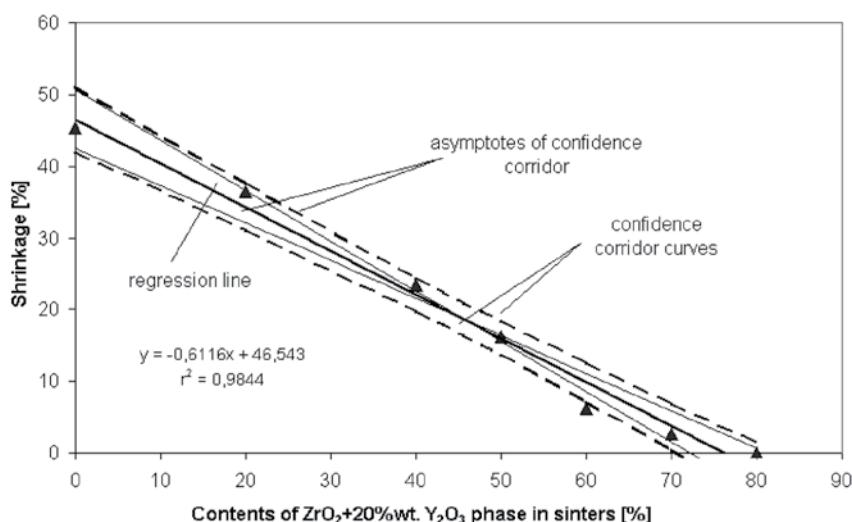


Fig. 3: Correlation chart with confidence corridor for HAp + (ZrO₂ + 20 wt. Y₂O₃) sinters

CONCLUSIONS

In the context of further application of HAp – based composites, a significant result of this work is the presented mathematical description, which enables assessment of amount of zirconium oxide in a powder mixture for which sinter shrinkage amounts zero.

The performed statistical verification of regression lines performed for sinters on hydroxyapatite base with addition of zirconium ox-

ide (ZrO₂ + 8 wt. Y₂O₃) and (ZrO₂ + 20 wt. Y₂O₃) enabled estimation, at the level of significance of $\alpha=0.05$ (for probability of 95%), that the ranges of zirconium oxide contents amount: (65% ÷ 76% wt.) and (71% ÷ 82% wt.), respectively.

ACKNOWLEDGEMENT

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SIMPLE TOOLS FOR ANALYSIS AND EXPERIMENTS IN MATERIAL RESEARCH

J. Menčík

Abstract

Material research deals with real specimens and computer models. In all cases, similar tools can be used for creation of abstract models and investigation of the influence of various factors. This paper explains several simple and effective tools, such as dimensional analysis and theory of similarity, statistical methods, determination of the number of measurements needed for obtaining confidence limits of a quantity or for verification of a hypothesis, the use of correlation and autocorrelation among the data, and finding of regression functions and check of their suitability.

Key words

research, experiments, statistical methods, dimensional analysis, regression analysis

Materials research investigates material structure and properties and also factors and quantities related to them and to their manufacturing. It aims at finding factors that influence the studied quantity, at quantifying their influence and describing their mutual relationships. Materials researchers work with real specimens as well as with computer models. In all cases, similar tools can be used for the investigation of various factors. The paper explains several simple and effective tools, such as dimensional analysis, theory of similarity, statistical methods, and correlation and regression analysis.

DIMENSIONAL ANALYSIS AND THEORY OF SIMILARITY

In the study of some phenomenon (e.g. wear), we seek first the quantities that can play some role. Then, we try to formulate the relationships between these variables, and to quantify the influence of individual factors. The pertinent relationship must contain all important quantities, but should not be more complicated than necessary. Dimensional analysis can help in looking for its proper form.

Quantities appearing in physical equations usually have some dimension. (Exceptions are coefficient of friction, Poisson's ratio and several other quantities.) When formulating an equation for the investigated phenomenon, one has to check whether the combination of all input quantities in this expression has the same dimension as the studied quantity. The dimensional analysis can reveal the proper form of the relationship. For example, when studying the deflection δ of a beam, we know that it is directly proportional to the load F and indirectly proportional to its bending stiffness S , and that it depends on beam length L . However, it could happen that we do not now if δ is directly proportional to L or to some power of L . We can suppose the general form of this relationship:

$$\delta = c F L^n / S, \quad (1)$$

where c is a constant and n is an unknown exponent. Replacing the quantities by their basic

units (m instead of δ and L , N instead of F , and Nm^2 instead of S), we obtain immediately $n = 3$.

A very useful in some cases is the conversion of the dimensional equations such as (1) into nondimensional form. A basic theorem of the dimensional analysis says that the relationship between N quantities, whose dimensions can be expressed by means of B basic dimensions (m , kg , $s...$), can usually be replaced by a relationship of $D = (N - B)$ dimensionless quantities or parameters. The use of nondimensional parameters can thus spare a lot of experimental work. If we want to study the influence of N factors on the quantity Y by making measurements for all possible combinations of the input factors, each of them being on L levels, we would need L^N experiments. For example, investigation of the influence of four factors, each on two levels („low“ and „high“), needs $2^4 = 16$ experiments. If the pertinent relationship can be expressed by means of 3 nondimensional parameters, the number of experiments drops to 8.

The simplest nondimensional quantities are obtained as the ratio of the dimensional quantity and its characteristic value, for example x/x_0 for length. Another, often used non-dimensional quantity is $(x - x_{\min})/(x_{\max} - x_{\min})$ or $(x - x_0)/(x_{\infty} - x_0)$, common, e.g., in the problems of heat conduction. In more complex cases, dimensionless parameters are usually sought in the form of product $\Pi = x_1^{n_1} x_2^{n_2} x_3^{n_3} \dots$. The unknown exponents $n_1, n_2, n_3, \dots$ are found by replacing the quantities $x_1, x_2, x_3, \dots$ by their dimensions $d_1, d_2, d_3, \dots$ (e.g. Nm^{-2} for d_1), and solving the equation $d_1^{n_1} d_2^{n_2} d_3^{n_3} \dots = 1$ for each basic unit (for example meter, m).

The nondimensional form of the characteristic equation also helps one not to forget some factors: it is impossible that some basic dimension appears only at one quantity. For example, the wear rate w of a tool is supposed to depend on the velocity v of mutual sliding and the mean pressure p in contact area. Now, if the formula for nondimensional parameter, $\Pi = w^{n_1} v^{n_2} p^{n_3}$ is expressed by means of their dimensions, $(m/s)^{n_1} \times (m/s)^{n_2} \times (N/m^2)^{n_3} = 1$, its solution would give (among other terms) $n_3 = 0$, which would mean

that the contact pressure disappears. However, we know that the contact pressure does play a role. Therefore, another parameter of the same dimension (N/m²) must be included into the characteristic equation – for example material hardness H .

The use of dimensionless quantities enables combination of results obtained for different specimens, and this can lead to a more universal law. Also, the results in nondimensional form are much more universal, valid for the whole class of similar objects, with similar geometry or physical properties.

STATISTICAL METHODS

Statistical methods are necessary if the studied quantity shows non-negligible scatter. They enable estimation of its range and the most probable value or the possible extreme values. They allow verification of various hypotheses and the determination of the number of experiments necessary for obtaining the results with a demanded accuracy. Their use is facilitated by commercial software.

Basic statistical information

The values of any measured quantity vary from test to test due to various influences (internal or external), which are out of our control, and which we denote as random. Therefore, it is recommended to repeat the tests or measurements several times. Only a few measurements are sufficient to obtain the basic characteristics, such as the average and standard deviation, which characterises the random variability. Tens or hundreds of measured values enable construction of a histogram, describing the distribution of the quantity (Fig. 1). It should be reminded that only some quantities can be described by symmetrical normal (or Gaussian) distribution. Properties such as strength or time to failure often have asymmetrical distribution (e.g. Weibull or lognormal), and their approximation by normal distribution could have bad consequences. Unfortunately, the number of tests is often limited. In such cases, the shape

of the distribution (e.g. symmetry) can be described by the coefficient of asymmetry (skewness) and coefficient of kurtosis. All these quantities belong to basic statistical tools and are available in common computer programs for data evaluation (e.g. Descriptive statistics in Excel). These programs are also able to construct histograms (Fig. 1).

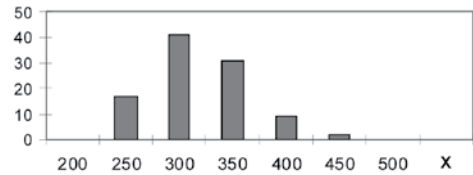


Fig. 1: Distribution of quantity x (frequency of occurrence)

Determination of the necessary number of measurements or tests

An important problem in planning of experiments is the determination of necessary number of measurements. This depends on the scatter of the measured quantity and on the demanded accuracy of the result, and can be determined using the formulae for confidence limits. For example, the mean value μ of some quantity x can be expected to lie between the limits

$$x_{ave} \pm t_{\alpha, v} s_x / \sqrt{n}, \quad (2)$$

where x_{ave} is the average and s_x is the standard deviation of x , $t_{\alpha, v}$ is two-sided α -critical value of Student's t -distribution for the confidence level α and $v = n - 1$ degrees of freedom; n is the number of measurements. The probability that the actual mean lies outside the confidence interval (2) is α . The half-width of this interval is $\Delta = t_{\alpha, v} s_x / \sqrt{n}$. From this expression, the number of measurements, necessary for ensuring the accuracy Δ in the determination of the mean value μ , is

$$n = (t_{\alpha, v} s_x / \Delta)^2. \quad (3)$$

Similar approach can be used for other quantities, and also for regression functions. If no information is available about the studied quantity, it is recommended to make a few measurements first in order to obtain the approximate value of standard deviation, and then to calculate the necessary number of tests via Eq. (3). If this number is high, it is reasonable to recalculate the standard deviation after about half of the tests, and to determine a more accurate value of n .

In materials research, one must often decide whether the influence of some factor (e.g. temperature) on the investigated quantity (e.g. strength) is significant, or if it can be neglected. Sometimes, we need to know whether the process or procedure „A“ is better than the process „B“. Due to random variability, the groups of data measured for both precesses can overlap. An objective tool for deciding is testing of hypotheses. This topic is described in any textbook on statistics. The necessary number of tests depends on the scatter of data, positions of both groups („average values“), and the degree of confidence we need for our decision. The formulae for testing are given in these textbooks (and are also available in common statistical software). These formulae can also be used for the determination of number of tests needed for rejection or acceptance of some hypothesis.

Correlation and autocorrelation

Correlation of two or more quantities means that changes of one quantity occur simultaneously with the changes of another quantity or quantities. The coefficient of correlation, $\text{corr}(x,y)$, characterises the strength of the mutual relationship between x and y : $\text{corr} = \pm 1$ means functional or deterministic relationship, while $\text{corr} = 0$ means that there is no relationship at all. Usually, the value of correlation coefficient is between 0 and 1 (or -1), lower for higher degree of random influences. However, even if the coefficient of correlation between two quantities is relatively high, it does not necessarily mean causal connection of both quantities. There could be a third factor, responsible for the changes of y as well as x . Therefore it is useful to check correlation among as many quantities (related to some phenomenon), as possible (e.g. strength, hardness, temperature and duration of heat treatment, content of some element in the material, etc.) Today, various software (including Excel) is equipped for single as well as multiple correlation analysis, and the only thing the researcher needs to prepare is a table containing the values of all quantites in the individual experiments (Tab. 1, left); the computer will then perform all the necessary work (Tab. 1, right). Due to random variability of the data, a check must sometimes be made whether the pertinent value of correlation coefficient is statistically significant or not.

Sample	Temp.	Time	Hardness	Strength
A	800	10.3	475	212
B	840	9.8	510	246
C	920	9.6	540	285
D	820	10	490	230
E	870	9.7	520	255
F	850	10.5	530	260
G	900	9.4	550	295
H	860	9.1	530	262

	Temp.	Time	Hardness	Strength
Temp.	1			
Time	-0.581	1		
Hardness	0.907	-0.545	1	
Strength	0.951	-0.573	0.980	1

Tab. 1: Multiple correlation. Left: Table of data, Right: Correlation coefficients

Correlation can sometimes be used for simplification of experimental work. For example, measurement of hardness is much easier than the measurement of strength. Thus, if strong correlation between strength and hardness has been proven, it is possible to replace strength testing by measurement of hardness, and use a suitable formula for the conversion of results to strength.

If measurements are done for a series of time points ($t_1, t_2, t_3, \dots$) or for various points lying in a line or in some area, it can be useful to check whether the measured values are correlated with the previous or surrounding values. For example, the maximum day temperatures can vary from day to day in a wide range, but the temperatures in summer are, in general, higher than in winter. This so-called autocorrelation can be revealed by the same tools as correlation. Instead of determining correlation between two different quantities x and y , we consider the correlation between the row $x_1, x_2, x_3, \dots, x_{n-1}$, and another row, obtained from the same series by shifting its values by one or more positions, e.g. $x_2, x_3, x_4, \dots, x_n$. In other words, instead of a series of couples $x_j - y_j$, a series of couples x_{j-1} and x_j is investigated. If autocorrelation has been revealed, it is possible to find a suitable regression function for expressing the „deterministic“ part of the total variability, and to reduce the scatter only to the true random part.

REGRESSION FUNCTIONS AND CHECK OF THEIR SUITABILITY

Regression functions are used for the description of relationships between various quantities. Some simple functions (linear, power-law, polynomial...) are offered by Excel and other universal software for data analysis. Constants in more complex expressions can be found using Solver and minimising the sum of squared differences between the measured and calculated values. The choice among several possible functions can be facilitated by visual check of individual fits or by comparing their coefficient of determination r^2 , which says what part of the total variability in the fitted quantity y can be explained by the regression function. Coefficient of determination is calculated as

$$r^2 = 1 - (s_{\text{res}}^2 / s_{\text{tot}}^2) , \quad (4)$$

where s_{tot}^2 is the total scatter of y , and s_{res}^2 is the residual scatter, i.e. the scatter of individual measured values $y_{m,j}$ around the regression function:

$$s_{\text{tot}}^2 = \sum (y_{m,j} - y_{m,\text{ave}})^2 / (n - 1) , \quad (5)$$

$$s_{\text{res}}^2 = \sum (y_{m,j} - y_{c,j})^2 / (n - 1) ;$$

the subscripts m and c mean measured and calculated, respectively, ave means the average, and n is the number of values.

Useful also is plotting of residuals ($y_{m,j} - y_{c,j}$). An example is shown in Fig. 2. Two regression curves A, B are hardly distinguishable (Fig. 2a), but the plot of their residuals in Fig. 2b shows

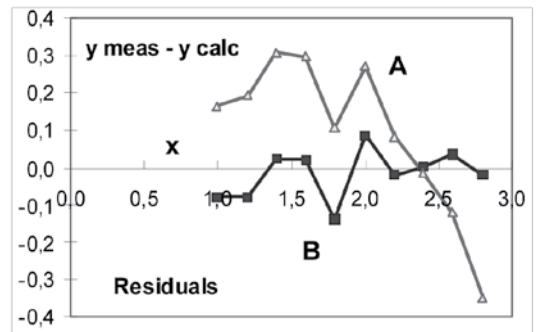
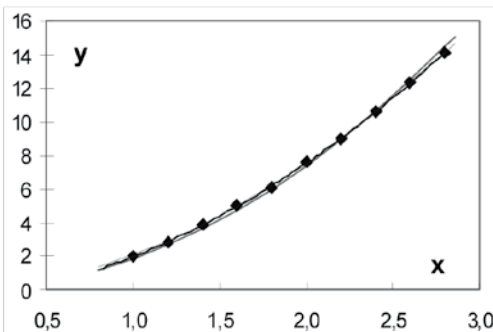


Fig. 2: Measured data fitted by two regression functions A, B (left picture) and differences between each regression function and the data (right-hand picture)

clearly that the function B, which is regularly distributed above and below the measured points, is better. While the y-scale in Fig. 2a is adjusted to the full range of y, the scale in Fig. 2b is adjusted to the maximum difference between measured and calculated values and shows thus the differences in much larger magnification.

ACKNOWLEDGMENT

The preparation and presentation of this paper was supported by the grant project GAČR 101/07/0727.

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EXPERIMENTAL RESULTS USING DILATOMETER FOR HYPEREUTECTICAL AL-SI ALLOYS'S BEHAVIORS

B. Varga, I. Száva

Abstract

It is well-known fact that the Al-Si alloys have several useful properties, which recommend their utilisation in car industry. In case of the internal combustion engines' pistons, the evaluation of the thermal dilatation magnitude is very important [1]. This evaluation can be realised / performed for: different sorts of Al-Si alloys, different kind of applied technologies and also during working process of the engine (at a very wide / large thermal region). The authors present some interesting measuring results (using a high-accuracy dilatometer) for Al-Si alloys (with 12-22% Si). The tested specimens were obtained for different solidifying conditions and for different heat treatments, too. The applied method (with dilatometer) allows also to evaluate the structural transformations on the high-speed cooled Al-Si alloys with or without heat treatment.

Key words

thermal expansion, aluminum- silicon alloys, precipitation, dilatometry, activation energy

Al-Si alloys have a number of remarkable technological and operational properties: excellent casting capacity, particularly of silumins of eutectic composition, good cutting capacity, good corrosion strength and good anti-friction properties. At the same time, the increase of the

silicon contents determines in these alloys the diminishing of the thermal dilatation coefficient, which reaches values close to the ones specific for cast iron (at approximately 40% silicon), Fig. 1.

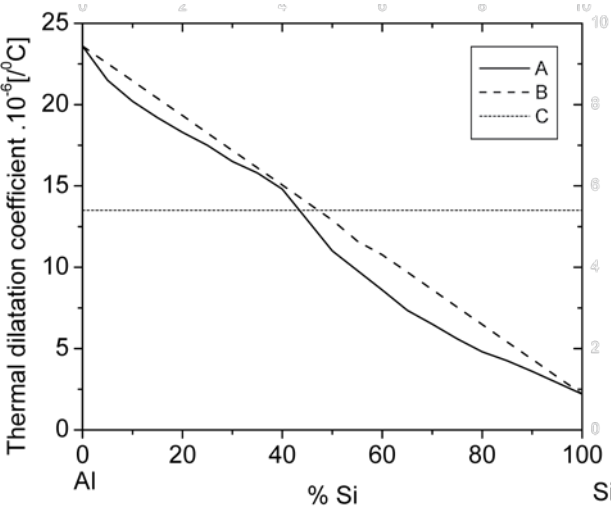


Fig. 1: Variation of the thermal dilatation coefficient in the Al-Si system: A – measured values: for chill-cast silumins (0 - 40 % Si,)and processed by atomisation pressing (50-100%Si) B – theoretical values, computed by the law of additivity; C – for the cylinder material (cast iron)

The structure of silumins used for engine pistons can be improved by intensifying the cooling rate, thus causing the finishing and globulization of the eutectic silicon separations. In this regard a new direction of piston processing entails casting with high solidification rates, for example by the melt spinning technology using spinning disks (made from thin tapes), followed by grinding and pressing.

The high cooling rates cause the silicon to remain in the α solid solution, what leads to the generation of a silicon over-saturated solid solution.

According to the Al-Si thermal equilibrium diagram silicon solubility in α solid solution is 1.65% at 577 °C eutectic temperature, and falls to 0% at room temperature.

No.	Cooling rate [°C/s]	Silicon concentration in the alloy [%]			
		1	2	4	8.3
1	Equilibrium	0	0	0	0
2	1	0.1	0.3	0.5	0.7
3	10	0.2	0.4	0.6	0.8
4	100	0.3	0.5	0.7	0.9
5	1.000	0.5	0.8	1.1	1.4
6	10.000	0.8	1.1	1.5	2.2
7	100.000	1	1.5	2.4	3.3

Tab. 1: Silicon concentration in α solid solution for various cooling rates and compositions

Test piece no.	Processing technology	Composition	Dimensions [mm]
1	Steel chill casting	Industrial Al-Si 12%	10 x 80 x 150 – ingot
2	Graphite mould casting		40 x 40 x 150 – ingot
3	Sand mould casting		40 x 40 x 150 – ingot
4	Casting by melt spinning (copper spinning disk)	Al-Si 12 %	0.03 x 4 – tape
5	Casting by melt spinning (steel spinning disk)	Al-Si 22 %	(0,05 – 0,1) x 5 tape

Tab. 2: Part dimensions depending on the processing technology

Tab. 1 presents the concentrations of silicon in α solid solution depending on the applied cooling rate [5].

During subsequent processing (heat treatment, pressing) the super-saturated solution decomposes, thus affecting both its structure and the product properties. It should be mentioned that the application of heat treatments also envisages the dimensional stabilizing of the piston.

Dilatometric determinations allowed the computation of the activation energy for the silicon precipitation process in the super-saturated α solid solution [2, 3, 4].

The paper discusses the dilatometric study of the structural transformation occurring in eutectic and hypereutectic silumins solidified at various cooling rates.

EXPERIMENTAL DETERMINATIONS

The experimental procedure included two compositions, as shown in table 2. For the first alloy two compositions were processed: an industrial alloy (Si-12.5; Cu-0.08; Mn-0.01; Mg-0.02, Zn-0.05; Fe-0.4 and Pb-0.04%), and one obtained from pure alloying elements.

The structural modifications of the eutectic silumins were achieved by the following processing technologies: sand casting, steel and graphite casting, by melt spinning. Table 2 shows the dimensions of the parts obtained by the mentioned technologies.

These processing technologies have ensured cooling rates between $1 \cdot 10^5$ °C/s. For these cooling rates the resulted structures are metast-

able, that is out of equilibrium. This can be established by the quantity of silicon retained by the solid solution.

During heat treatment, thus during the dilatometric analysis of the test pieces included, the main transformation will be that of silicon precipitation in the super-saturated α solution.

For dilatometric analysis test pieces of 6 mm diameter and 10-20 mm were taken and studied by means of a LINSEIS, L75/230 dilatometer.

Figure 2 shows the dilatometric curves and the corresponding derivatives for test piece no. 3 of table 2 for two heating rates, indicated in brackets (in °C/min).

The activation energy could be determined by Kissinger's equation (1), under consideration of the condition for the continuous heating of test pieces

$$\ln \frac{v}{T_m^2} = - \frac{E_a}{R \cdot T} + M \quad (1)$$

where:

T- temperature;

v- heating rate in °C/s

R- universal gas constant, $R = 8.3144$ [J/mol.K];

M- constant;

T_m - maxim point of the dilatation curves derivative, in Kelvin.

By the processing of the experimental data the value of the activation energy could be determined for the silicon precipitation process in the super-saturated solution.

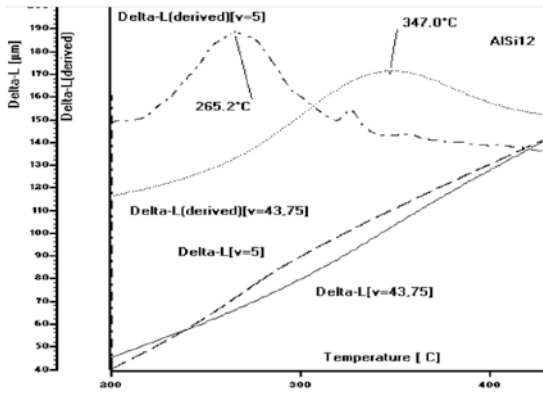


Fig. 2: Dilatometric curves and corresponding derivatives for test piece no. 3

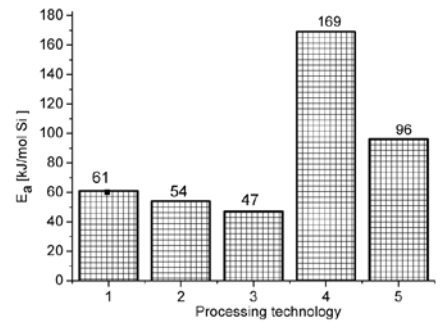


Fig. 3: Variation of the activation energy depending on processing (cooling) conditions

Figure 3 presents the values of the activation energies depending on the casting (cooling) conditions of the analyzed test pieces.

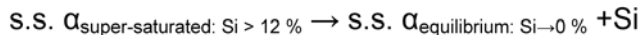
In the case of test pieces no. 1 – 3 silicon precipitation takes place on the silicon separation existing in the structure of the alloy. In this case the structural transformation can be described by the following equation:



In the case of test piece no. 4, solidified at a high cooling rate, the entire quantity of silicon has remained in the α solid solution, as confirmed by the diffractogram of figure 4. It can be noticed that only lines corresponding to aluminium appear.

Silicon precipitation in the super-saturated solution was generated by the heat treatment applied during the dilatometric analysis of the test piece, as shown in figure 5. In this case the structural transformation can be described by the following equation:

In this case the structural transformation can be described by the following equation:



Consequently silicon precipitation in the super-saturated solution includes, in this case, both germination and diffusion phenomena, what accounts for the value of the activation energy, which is significantly higher than for test pieces no. 1 – 3.

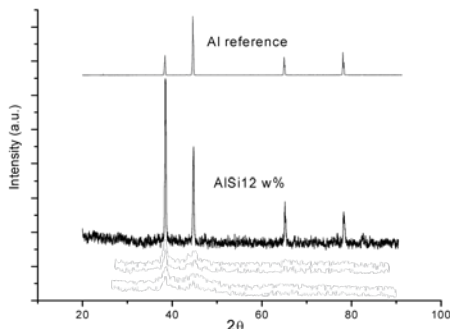


Fig. 4: Diffractogram for test piece no. 4

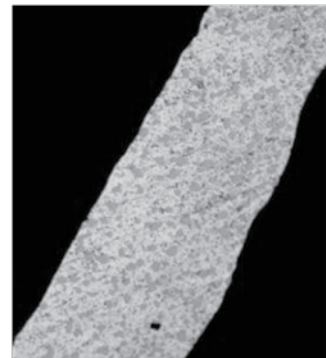


Fig. 5: Microstructure of test piece no. 4; tape thickness: 30 μm

In the case of test piece no. 5 the value of the activation energy is again smaller, as in the structure of the alloy cast in tape shape the precipitation process was significantly facilitated by the silicon separation present in the structure. The presence of silicon separations is confirmed by both the X-Ray diagram shown in figure 6 and the microstructure of the alloy formed by dendrites of α solid solution and eutectic (α + Si), Fig.7.

CONCLUSIONS

Cooling conditions influence the value of the activation energy of silicon precipitation, in the sense of its decreasing with an increasing cooling rate.

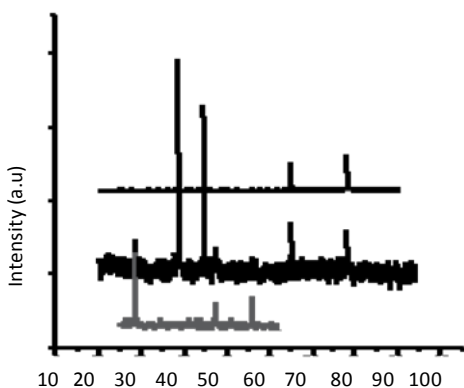


Fig. 6: Diffractogram for test piece no. 5

In the case of thin tapes from AlSi12 alloy, silicon precipitation in super-saturated α solid solution also entails a germination process, what causes the activation energy to be significantly greater than in the case of solid solution decomposition involving solely diffusion processes.

The values obtained for the activation energies are in good agreement with those obtained by other methods like DSC, TEM [1, 2].

ACKNOWLEDGEMENT

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Fig. 7: Microstructure of test piece no. 5, after casting

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TESTING DEVICE FOR ELASTIC COMPONENTS OF COUPLING SYSTEMS

M. Procop, E. Chişu, I. Száva, P. Dani, B. Gálfi, J. Gergely, L. Lukács, B. Székely

Abstract

Were conceived two original testing devices destined to evaluate the stress-strain state of the elastic elements of one original (patented) coupling system, which allows the changing of the deteriorated elastic elements without taking to pieces of the whole coupling system. The elastic elements are some "Z"-shaped steel lamellas with rubber or Polyurethane part, forming together some compact parallelepiped elements. Their elastic properties determine the coupling system's properties. These devices allow to evaluate the elastic characteristics both for lamellas, rubber (or Polyurethane) part and for the assembled elastic elements, too. In this sense were conceived some original electric and inductive transducers. Are offered both the descriptions of the testing devices and the adequate calibration curves. Some further goals of the authors are to determine the elastic properties of these parallelepiped elements and to perform their optimization also from dynamical point of view.

Key words

testing devices, elastic elements, coupling system

Usually the coupling system's deterioration, especially the wear of its elastic elements, implies taking to pieces of the whole coupling system. This operation/work takes not only money, but a lot of part/amount from the precious working time. Such coupling systems' reparation, represents a very great disadvantage for the whole working system (for example: in a plant or in the oil extractive industry). The main author of this paper conceived and realized a new, patented coupling system, destined especially for the oil extractive industry. This new coupling system allows the elastic elements' changing without taking to pieces of the

system. This new system's elastic elements are formed from some "Z"-shaped steel lamellas with rubber or Polyurethane part, forming together some compact parallelepiped elements.

Their elastic properties determine the coupling system's qualities. For some further optimization of this new coupling system, the authors conceived and realized a special testing device, destined to establish the elastic properties of these compact parallelepiped elements.

THE TESTING DEVICES DESCRIPTION

One of these original testing devices is destined to analyse the whole assembled (parallelepiped) elastic elements (see Fig. 1). Its main parts are: the rigid plates 1, 5, fixed between the universal testing machine's loading disks, the electric strain gage force transducer 4, which holds the special plate 3, with the tested/analysed compact parallelepiped element 2, respectively the inductive displacement transducer 6, which indicates the displacement d with a good accuracy (for 2.1 mm the corresponding electric signal is approx. 400 mV). In figure 2 is shown the inductive transducer's calibration curve and in figure 3: the calibration curve of the force transducer 4.

On can remark the good linearity of these transducers, even they are home-made ones.

The tested/analysed compact parallelepiped element 2, is in fact the subassembly of the "Z"-shaped steel lamellas with rubber or Polyurethane part. For its real strain-state evaluation, they are foreseen (the steel lamellas) with two electric strain gages T1 and T2, connected in half (Wheatstone) bridge (see figure 4). These measuring results are very useful for the Finite Elements Modelling of these subassemblies,

where the real contribution of the rubber/Polyurethane parts are quite difficult to estimate without these information.

The above described stand allows to test not only these subassemblies, but also the pure rubber/ Polyurethane parallelepiped elements.

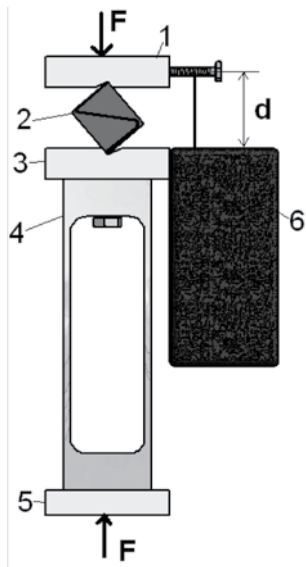


Fig. 1: The first testing device

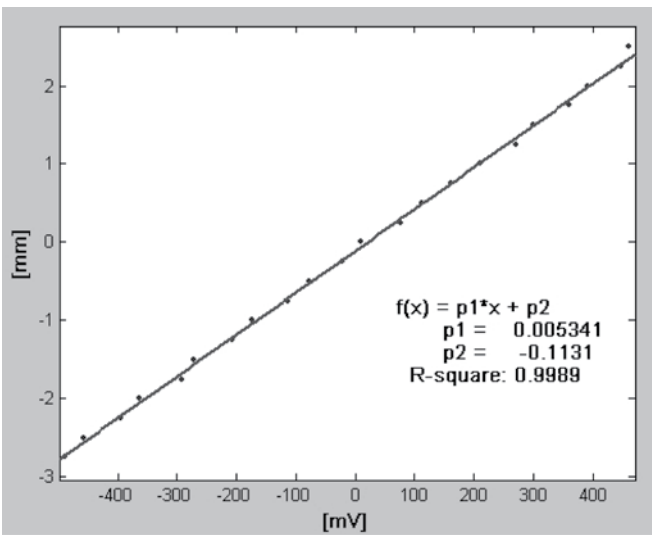


Fig. 2: The Inductive transducer's calibration curve

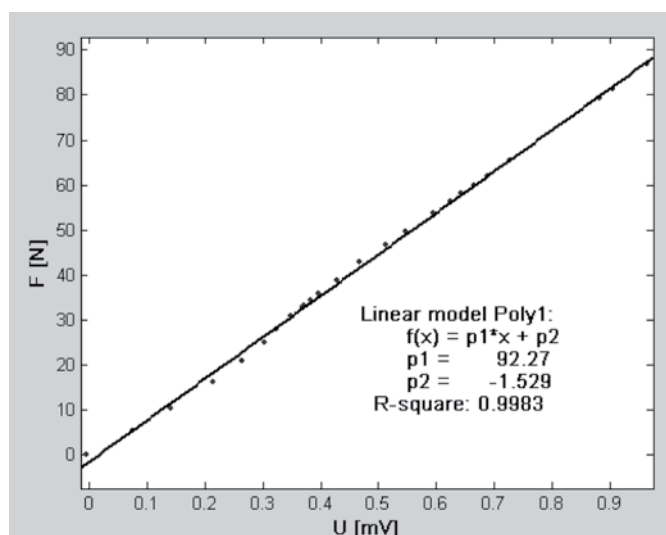


Fig. 3: The force transducer's calibration curve

In this case, the tested specimens are disposed/positioned with their faces parallel to the acting surfaces of the plates 1 and 3.

To evaluate the "Z"-shaped steel lamellas' own/singular elastic behaviours, the authors conceived a second, high-sensitivity testing de-

vice (Fig. 5). It is built up of the rigid plate 1 and the lever system 4, which allows a rotation of its horizontal rod (with a small mechanical resistive force) under the applied load F_0 , measured by mean of the high-sensitivity electric transducer 5 (with its calibration curve shown in figure 6).

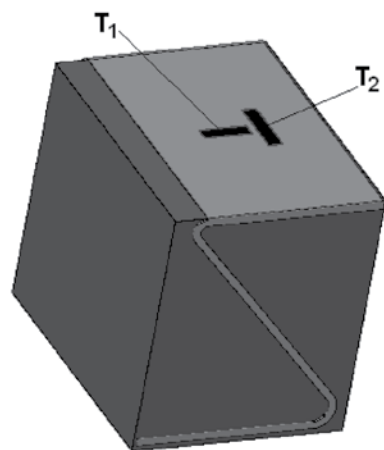


Fig. 4: The compact parallelepiped element

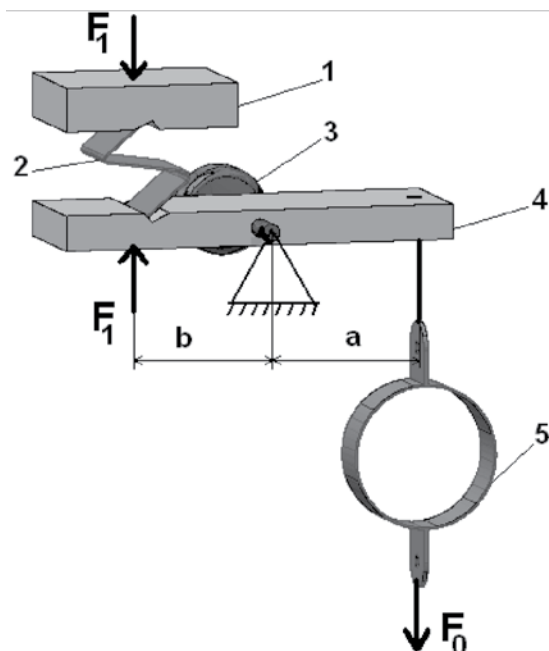


Fig. 5: The second testing device

This force F_0 will load the tested “Z”-shaped steel lamellas 2 proportional in the ratio of the arms ($F_1 = F_0 x a/b$). In this case, the displacement will be measured by mean of a special transducer 3, having a very small mechanical resistive force.

To evaluate the real strain-state of the lamellas, they were foreseen with two electric strain gages T1 and T2 , connected in half (Wheatstone) bridge (see figure 7).

CONCLUSIONS AND FURTHER GOALS

Using these original testing devices, the authors intend to establish for different kind of elastic subsystems their real mechanical properties to be adequate for different kind of industrial requirements.

Based on these experimental results, the authors will perform some high-accuracy Finite Elements modelling of these special elastic subsystems.

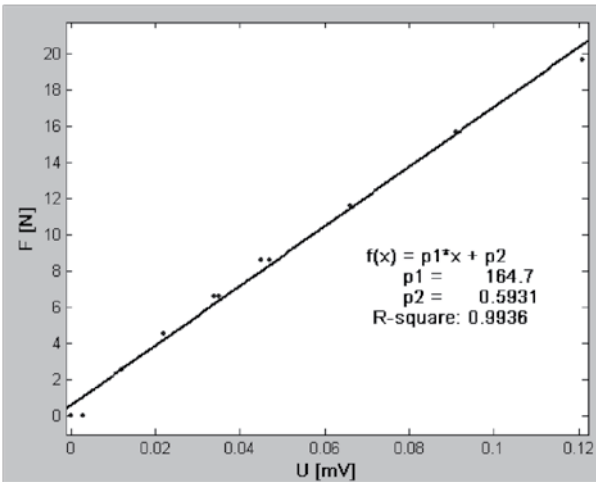


Fig. 6: The high-sensitivity transducer's calibration curve

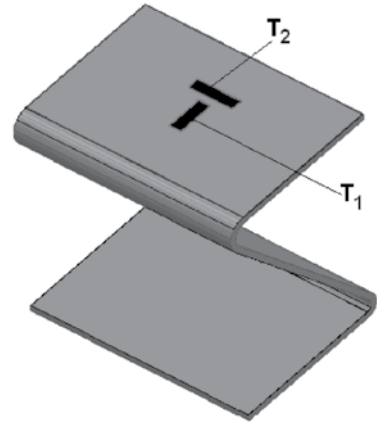


Fig. 7: The “Z”-shaped steel lamellas

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K. Titz, K. Konečná, M. Špok, M. Tvrđý

Abstract

The investigation of the causes of fracture of rolls in cold rolling mill revealed the possible metallurgical effects on the premature cracking of rolls. All the found experiences from the fracture surfaces are the same as those obtained by other authors. Anyway we would like to emphasize the effect of hydrogen, which may be not omitted at the final discussion. The proof is the fracture appearance and the hydrogen content in the steel.

Key words

fracture, roll

Spalling of the surface layer of rolls in cold rolling mills is frequently observed especially, when the manufacturer of rolls is omitting one of important prerequisite of good life of rolls, i.e. degasation of melts or reduction of impurities content. The spalls have the origin below the surface, some 10 - 30 mm, and they are starting by fatigue crack usually on inclusions. The typical picture of spalling peace is shown in the Fig. 1.

The original crack is of the band character and is growing by the fatigue mechanism in the circumferential direction below the roll surface. In the first view on the crack we have imagined the type of stressing during rolling and this way we have observed not only the fatigue striation, but also the smashing effect of the fatigue crack surface by every rolling cycle. This character of fracture is shown in the Fig. 2.

During the rolling life of rolls there are many periods of stand-by character and this way the stress in roll may form the good conditions for the growth of cracks by the presence of stress and hydrogen environment. The process is for years known as the hydrogen stress cracking and the appearance of such cracks is visible in the Fig. 1.

Thy hydrogen cracking is known also from the microfractographic examinations. The fracture surface is formed by both the transgranular cleavage and the intergranular brittle surfaces. The appearance of such fracture is visible from the Fig. 3. As shown in the Fig. 1, the supposed hydrogen assisted fracture is of circular character and is forming so called large flake. The final fracture is of natural character and is formed by prevailing transgranular cleavage and transgranular ductile fracture Fig. 4.



Fig. 1: Spalling fracture of the roll

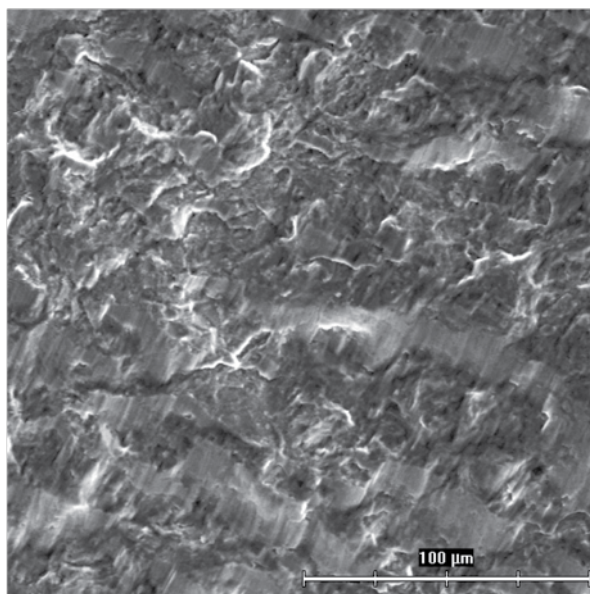


Fig. 2: Origin of fracture formed by fatigue striations

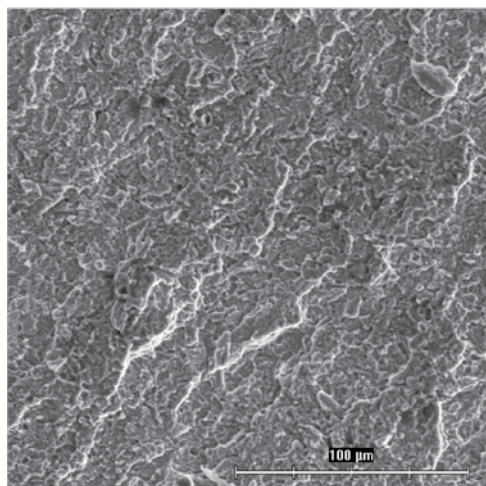


Fig. 3: Partially intergranular fracture which should be the hydrogen assisted cracking

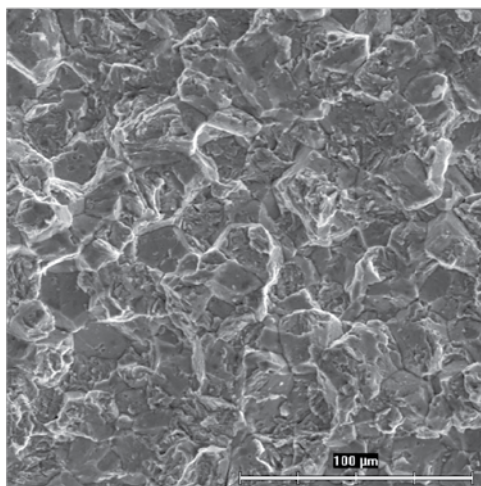


Fig. 4: Final fracture, formed by the transgranular mechanism (transgranular cleavage)

CAUSES OF SPALLING IN COLD WORK ROLLS

First of all the origin of spalling is the inclusion content in steel. This is forming the origin fatigue crack with the further development into final fracture. The second cause is the increased gas content in steel. In such a case the increased oxygen content may influence the total inclusion content in steel and the hydrogen content is responsible for the slow crack growth (with the mechanisms of transgranular cleavage and intergranular cleavage content). To elaborate the proper requirements for the rolls, it is necessary to demand the high quality of steels, produced by the newest steel technology, which result in low gas content in steel, decreased inclusion content, and to use the moderate carbon content 0.4 – 0.5 %C to prevent the formation of plate martensite.

Also, the final non-destructive control by the eddy current method or by surface Rayleigh waves may be the proper way how to increase the starting performance of the rolls. The one of very promising methods is the acoustic emission and it is one of our future ways of the research.

CONCLUSIONS

1. Modern rolling mills require the modern steel production of rolls.
2. The modern steel technology production requires the low gas content, low inclusion content and higher purity of steels.
3. The final non-destructive control is based not only on standard methods, but also on eddy current testing, surface Rayleigh wave testing and basically also the acoustic emission, which at least increases the final roll life.

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USE OF ACOUSTIC EMISSION DURING TESTING OF PRESSURIZED BOTTLES

J. Crha, K. Titz, L. Vavrečka, M. Tvrđý

Abstract

Acoustic emission technique has been used for detecting the suspected flaws in the pressurized composite bottles. The pressure has been directed up to the final fracture of the bottle.

It is stated that the bottle is preserving the Kaiser rule. The fracture of the bottle occurred at the pressure 1003 bars, i.e. under the pressure which is double in comparison to proof pressure. AE monitoring of pressurized bottle gives the good possibility to predict the final fracture.

Key words

fracture, composite bottle, acoustic emission

Acoustic emission is very powerful mean of non-destructive and destructive testing. If the ultrasonic testing is taken as the sophisticated eye, then the acoustic emission is the intelligent ear in the material. The role of acoustic emission is twofold: First of all, it detects the stress waves, emitted during the microcracking events and during the crack growth [1,2]. Secondly, it detects the mass effects, like e. g. the moving dislocations during the yielding of steel or non ferrous metals, martensitic transformation or the internal stresses. What is the most important, the acoustic signal is not following the displacement y on the surface, even not the rate of movement of surface (the surface velocity), dy/dt , but the acceleration of the surface, d^2y/dt^2 . This way the sensitivity of measurements is extremely high and the disturbing noises (e.g. the operation, traffic, etc.) may be suppressed.

The acoustic emission technique has been applied to the subsidiary measurements of the activities of the acoustic emission sources in the composite bottle, where the original lining has been made of the aluminium alloy and the final thickness has been determined by the carbon fibre.

The producer promised the good life expectancy and good operation facilities of the pressurized composite bottle.

EXPERIMENTAL TECHNIQUE

The experimental technique is schematically shown in the Fig. 1. We have used two sensors (accelerometers) attached to the bottle. The attachment is made by special sticking mass which is not disturbing the acoustic signal. The

bottle with the sensors has been put into thick wall tube to prevent the eventual dispersion of broken parts. The pressurizing has been imposed by water through the pressure pump. The AE sig-

nal is led through the preamplifiers to data acquisition box and further to the computer. Both the pressure and the counts of acoustic emission were plotted against the time of experiment [3].

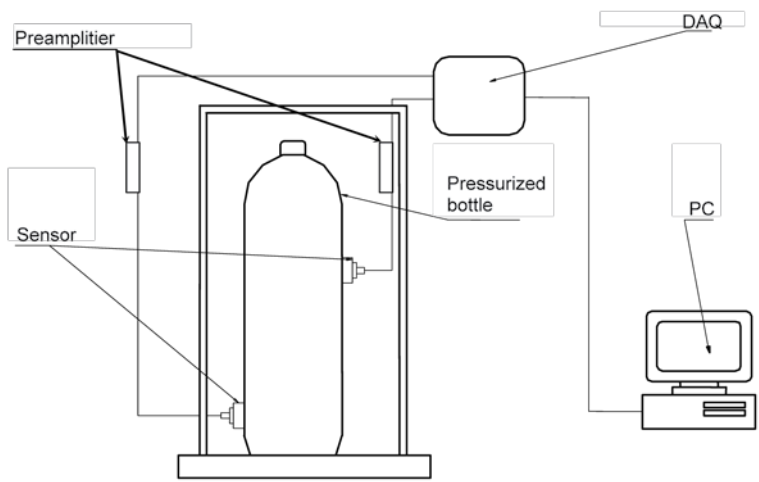


Fig. 1: Scheme of experiment

RESULTS AND DISCUSSION

The overall view on the time dependences of pressure and counts per second is shown in the Fig. 2. The Fig. 3 is representing the same dependences but the AE sensors have increased sensitivity.

The first stage of experiment is showing the time dependence of pressure up to 300 bars, which is demonstrated in the Fig. 4. As visible from the Fig. 4, the pressurizing to 300 bars, which has been provided by the firemen crew, has no effect to AE signal, because of Kaiser effect, i.e. up to this pressure there is no evidence of anything noise. But after reaching this pressure value,

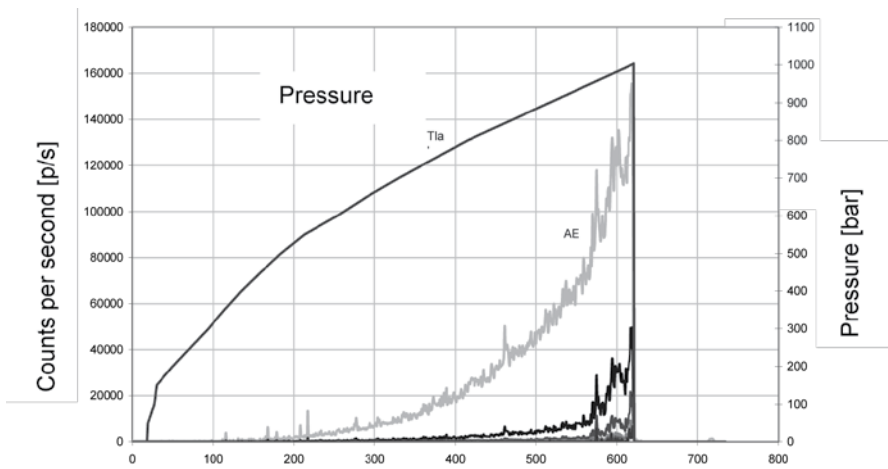


Fig. 2: The time dependence of pressure and counts of acoustic signal during the whole testing time

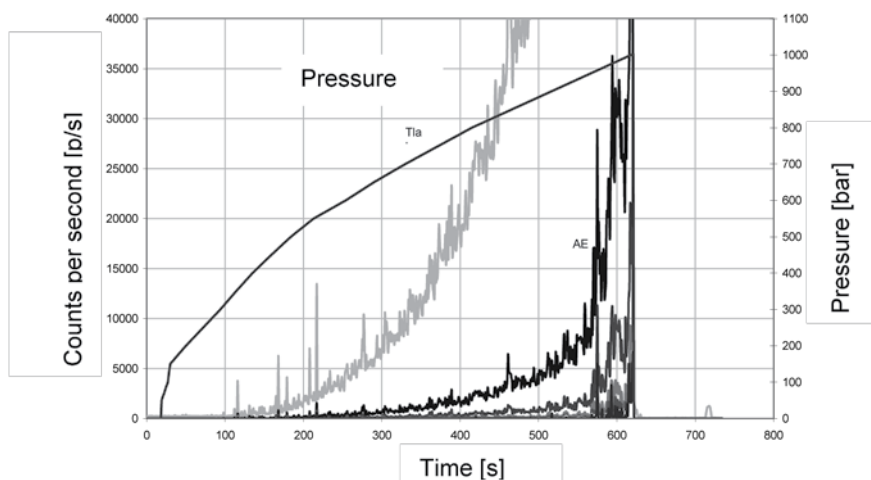


Fig. 3: The time dependence of pressure and counts of acoustic emission signal, the latter being monitored at higher sensitivity of the sensor

there is a progressive increase of the AE counts up to the pressure value 450 bars, which is the proof test value. The evolution of pressure and acoustic signal up to 900 bars is shown in the Fig. 5 and the final stage at the pressure level 1003 bars in the Fig. 6. It may be remarked that the number of counts per second is all the time progressively increasing and at final fracture the signal is reaching the saturation level. See also the change of the slope of the pressure-time dependence at the pressure level cca 540 bars, where the yielding of the aluminium lining has occurred. After such a moment there is only the chance of the carbon fibres to hold the overall consistency of the bottle up to the final fracture.

At this moment the processes have unlimited course and we could only remark the occurrence of final fracture. The fracture of aluminium lining consists of plastic yielding, but from the scanning microscope pictures we see that the fracture, even under the complete shearing, contains the fragments of intergranular fracture (Fig. 7).

Before the conclusions we may only suppose that the process of fracture of the pressurized bottle is first of all safe, the fracture occurring at the pressure level which is more than twofold in comparison to proof test. Secondly, there may be uncertainty due to partially intergranular fracture. The third experience is that the proc-

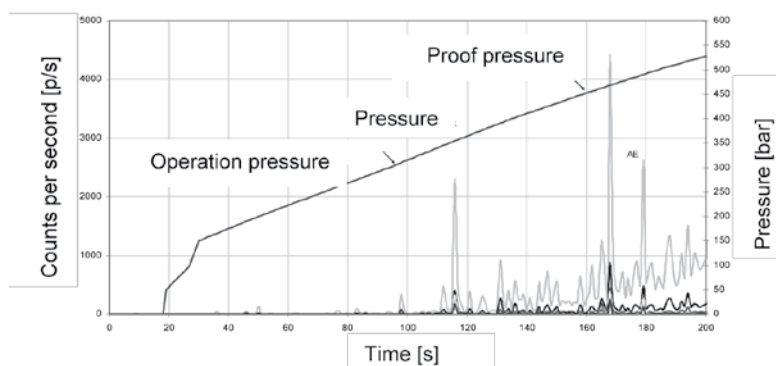


Fig. 4: Time dependence of pressure test during the first stage

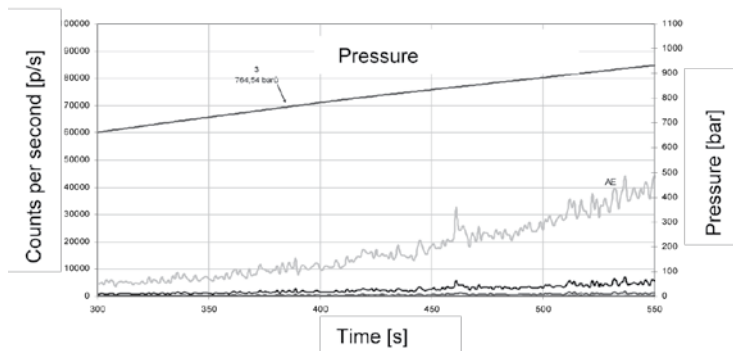


Fig. 5: Time dependence of pressure and counts, second stage

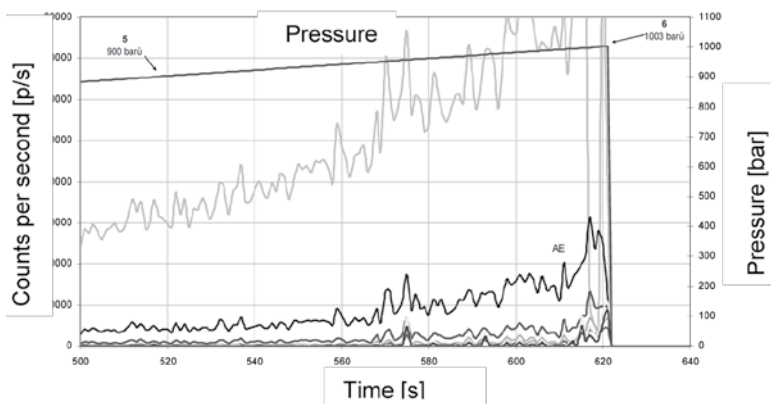


Fig. 6: Time dependence of pressure and counts, third stage

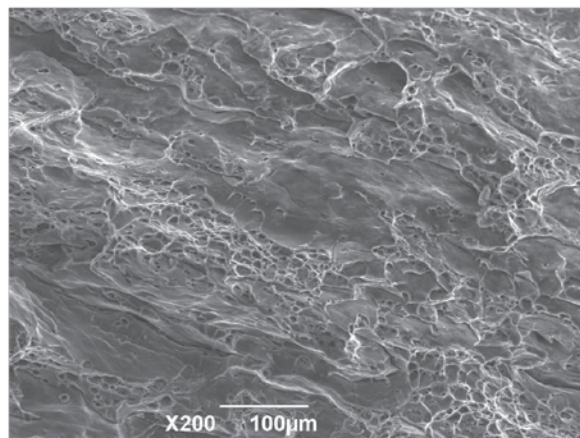


Fig. 7: Fracture of aluminium part of the bottle

ess of fracture of composite bottle is far from the point of serious knowledge, where more than one stage is present.

CONCLUSIONS

1. The Kaiser effect has been observed during the first stage of pressurizing of the composite bottle.

2. The fracture of the bottle occurred at the pressure 1003 bars which is twofold higher value in comparison to proof testing value. It is forming sufficient stage to the prediction of destruction.
3. The AE monitoring of pressurized bottle is giving the good possibility to the extension of the bottle life under the standard regulations.

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X-RAY DIFFRACTION STUDIES ON THE CRYSTALLINE MORPHOLOGY IN THE COMPOSITES POLYPROPYLENE WITH GLASS FIBRE

R. Caban, Z. Nitkiewicz

Abstract

This work aimed to identify the crystalline phases which appear in polymeric matrix as well as to determine the degree of crystallinity for composite based on the matrix of polypropylene reinforced with glass fibre. Investigations by means of X-ray diffraction analysis method were performed using SEIFERT diffractometer of XRD 3003 T – T type. The filtered radiation of the copper anode lamp, $\lambda = 0,154$ nm was applied. For investigated composites the presence of several types of polymorphous polypropylene has been found. The crystalline part of the matrix for the investigated composites is composed of α phase which crystallizes in monoclinic lattice and β phase which crystallizes in

hexagonal system. Moreover, it has been found that amorphous phase in the investigated composites is made of strongly oriented smectic phase of polypropylene.

Key words

X-ray phase analysis, degree of crystallinity, materials, composites

Thermoplastic-based composites are becoming more popular in many application fields due to the possibility of combining the toughness of thermoplastic polymers with the stiffness and strength of reinforcing fibers, and their ultimate properties depend on the characteristics of the matrix and fibers, as well as on the adhesion strength at the interface. In addition, these composites can be easily processed by common techniques such as injection and compression - molding. In order to be applicable for a massive and economic production the matrices have to be economic, easily available and well established. For this reason, polypropylene (PP) is one of the most used polymers for fiber – reinforced composite, especially due to economic reasons, ease of processing, environmental and working security, and recyclability [1]. The quality of composites is determined by the internal structure of a polymer which makes up a matrix as well as the type of reinforced phase [2, 3]. The structure of a polymer is of a crystalline-amorphous nature while better properties are obtained when the structure is predominated by the ordered crystalline phase fraction. Crystallinity is one of the most important parameters of the two – phase, lamellar model of polymer structure. It is defined as the ratio of the mass of crystalline phase to the total mass of the polymer. The physical and mechanical properties of polymers are profoundly dependent on the crystallinity, and various methods have been elaborated to determine this parameter [4]. Most frequently, the X-ray diffraction method

is used. The method is based on the assumption that it is possible to separate the scattered intensity contributions arising from crystalline and amorphous regions.

This work aimed to identify the crystalline phases which appear in polymeric matrix as well as to determine the degree of crystallinity for composite based on the matrix of polypropylene reinforced with glass fibre.

MATERIALS AND EXPERIMENTAL PROCEDURE

This work presents the results of investigations of composites made of the granulates by Polimarky (Rzeszow, Poland). These granulates contained polypropylene - Malen P J – 400 produced by Petrochemia Płock and glass fibres with E symbol. The glass fibres with final length 6 mm were covered by silane preparation. The investigations encompassed the composites on the polypropylene matrix which contained 30% of the glass fibre (GF). For the comparison purposes the matrix material was also tested.

Samples for investigations were prepared by means of injection with Krauss – Maffei injection machine (KM65 – 160C1 type). Part of the material was processed by heat treatment in the form of soaking at the temperature of 130 °C in the air. Soaking rate amounted to 0,015 °C/s, soaking time 900 s per mm of the sample thickness, cooling rate 0,010 °C/s.

Investigations by means of X-ray diffraction analysis method were performed using SEIFERT diffractometer of XRD 3003 T – T type. The filtered radiation of the copper anode lamp, $\lambda = 0,154$ nm was applied. The stepped method of measurement within the range of scattering angles of 2θ from 1° to 60° with the step of $0,1^\circ$ has been used. The measurements of the scattered radiation were performed both in crosswise (“r”) and lengthwise (“s”) orientation of the sample in relation to primary beam. The concentration of crystalline phase of polypropylene (i.e. crystallinity degree S_k) was calculated in the form of the quotient of the total of integral intensities of crystalline reflexes to the integral intensity of diffraction curves.

RESULTS AND DISCUSSION

The analysis of X-ray diffraction patterns was based on the literature data concerning characteristic diffraction reflexes for polymorphous α types (monoclinic) or β (hexagonal) of polypropylene and polypropylene smectic phase [5, 6]. In most of the obtained diffraction patterns a few strong diffraction reflexes are to be seen (Fig. 1, 2). They come from the lattice planes: (110), (040), (130) and also (111) and (131), characteristic for the α form and from the crystallographic plane (300) – for β form.

Examples of comparison of X-ray diffraction patterns determined for the samples positioned crosswise – “r” and the lengthwise – “s” in relation to primary beam have been presented in the Fig. 1, 2.

While comparing diffraction patterns obtained for the crosswise and lengthwise samples in relation to the primary beam it can be assumed that the amorphous phase in composites both for polypropylene and for polypropylene domains is composed of strongly oriented smectic phase of polypropylene. Moreover, distinct dislocation of diffraction reflex can be observed. This proves a very high degree of orientation of crystallites of polypropylene in relation to longitudinal axis of the investigated samples.

Taking the abovementioned into consideration as compared to the results of the investigations performed for the composite which contains 30% of glass fibre after soaking it should be observed that very low intensity of the diffraction reflex which comes from the (300) plane or virtually non-existence of such a diffraction reflex can be connected with the effects caused by the orientation rather than by lack of β type in this individual case. Hence, during diffraction pattern analysis of this sample the existence of β polypropylene was also taken into consid-

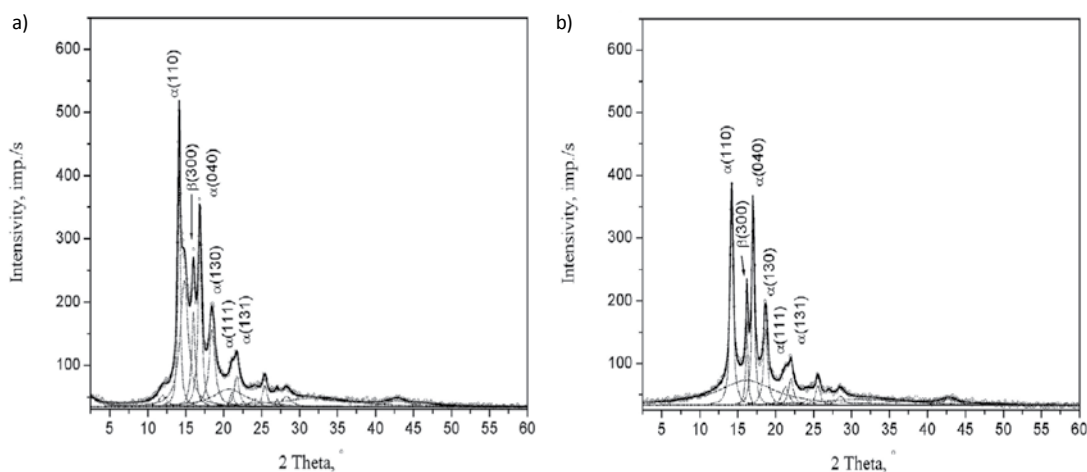


Fig. 1: Diffraction curve for the composites: PP + 30% GF: a) PP+30%GF – “r”, b) PP+30%GF – “s”
(— experimental curve, --- fitting curve, ---- reflexes from crystalline and amorphous phase)

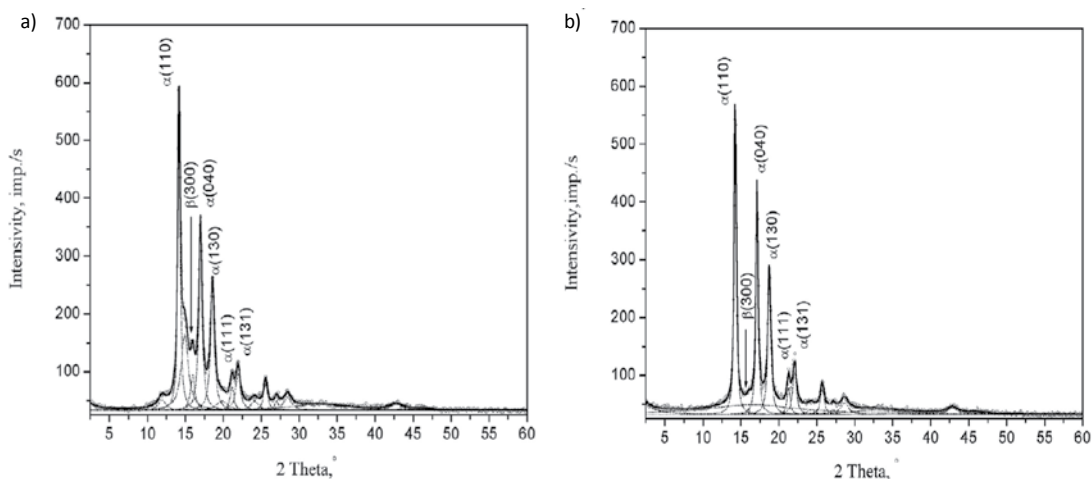


Fig. 2: Diffraction curve for the composites: PP + 30% GF ob.: a) PP+30%GF ob. – “r”, b) PP+30%GF ob. – “s” (— experimental curve, — fitting curve, ---- reflexes from crystalline and amorphous phase)

Material		$S_c, \%$
PP	„r“	67,8
	„s“	73,7
PPob.	„r“	71,8
	„s“	79,5
PP+30% GF	„r“	53,0
	„s“	46,8
PP+30% GF ob.	„r“	70,0
	„s“	59,4

Tab. 1: Values of degree of the crystallinity of the investigated samples determined by X-ray method

eration. Changes in intensity of the reflex (300) which come from the b form show that this form is less stable than monoclinic type of the α .

Implementation of the fibres into the polymeric matrix caused the decrease in crystallinity degree determined by the X-ray method (Tab. 1). This proves that glass fibre does not work as factor which causes nucleation of the matrix crystallites.

From the analysis of the crystallinity degree compared in the Tab. 1 it results that soaking causes the increase in crystallinity phase fraction which occur in polymeric matrix of the investigated composites. The reason of this fact is a repeated crystallization which takes place during heating and soaking of the sample at the temperature within optimal crystallization rate and as a result slow cooling.

CONCLUSION

The crystalline part of the matrix of the investigated composites composes of α phase which crystallizes in monoclinic lattice and the β phase which crystallizes in hexagonal system. The amorphous phase in the investigated composites is in the form of strongly oriented smectic phase of polypropylene. As a result of soaking, in the structure of the investigated composites the increase in fraction of crystalline phases which appear in polymeric matrix occurs. The introduction of fibres into the polymeric matrix has caused the decrease in crystallinity degree.

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CRYSTALLIZATION ABILITY OF ALUMINOSILICATE (DIABASE) GLASSES FOR THE PRODUCTION OF FIBROUS INSULATING MATERIALS

M. Lubas, P. Wyszomirski

Abstract

Glasses used for the production of fibrous insulating materials are made from raw materials, mainly basalts.

In the work were applied for the preparation of aluminosilicate alloys, a new raw material – diabase of Niedzwiedzia Gora deposit in Poland. The crystallization ability of molten diabase obtained was determinate by annealing of its glass at various temperatures during different times.

Depending on the raw material used as well as the temperature of heat-treatment amorphous or crystalline materials were obtained. The crystalline degree and phases were identified based on X-ray diffraction studies and density differences glasses. The result was found that magnetite/titanomagnetite crystallized in the first step. Then pyroxenes phases of diopside or augite type appeared in the systems.

Key words

ability crystallization, diabase glasses, degree crystallization, insulating materials

In the last years high increase of insulating building materials wear, including mineral wool, has been observed. In modern technologies one of important stages is planning and proper raw materials selection. New technological solutions are explored which provide new materials of better resistance and functional properties. New rock raw materials are searched from which silicate alloys can be obtained and they have low crystallization ability and better properties comparing to basalts traditionally used for such production. Among interesting raw materials there are: melaphyres, gabbros, amphibolites and diabases [2,5].

The work presents the properties of diabase glasses – perspective in terms of mineral wool production.

MATERIAL FOR EXPERIMENTAL

The raw material used for this work was diabase, coming from deposit in Niedźwiedzia Góra near Kraków. This raw material is now used only for road building mainly to produce broken stone.

XRD and microscopic SEM/EDS analysis presented in previous works [4] showed that the main components of the analyzed diabase are: plagioclases and pyroxenes (diopside, hypersthene, augite) as well as titanomagnetite, ilmenite and apatite.

In order to estimate crystallization ability of diabase glass, a batch of raw material containing 100% diabase was prepared, placed in alundum crucible and melted in electrical furnace in 1400°C. The melted sample was held at this temperature for two hours, than poured out onto a steel plate to quench than rapidly with the formation of glass - material for the experiment. (Tab. 1, Fig. 1).

Crystallization ability of diabase glasses

In the work crystallization ability of aluminosilicate diabase glasses was estimated and the products of its crystallization were identified. In order to explore profoundly crystallization ability, glass samples were annealed in gradient furnace in different temperatures during the period of 2 and 4 hours. Crystallization products were examined by XRD analysis with the use of RICH SEIFERT XRD 3003 diffractometer, applying CuK α radiation. Crystallization degree was estimated on the basis of X-ray analysis and glass density change before and after annealed. The thermal differential analysis was performed using derivatograph constructed by Paulik, J. Paulik and L. Erdey.

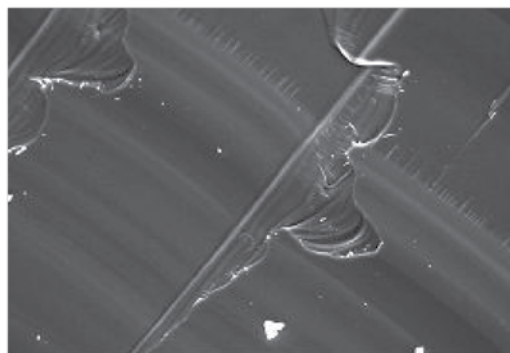


Fig. 1: Diabase glass melted in 1400°C

Thermal analysis (DTA) enabled to estimate characteristic temperatures: transformation temperature T_g - 669°C and crystallization temperature T_{c1} = 920°C, T_{c2} = 1093°C, used for estimating glass thermal durability index by dependence [7]:

Component	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃ calc.	MgO	CaO	TiO ₂	Na ₂ O	K ₂ O	P ₂ O ₅	MnO	Suma
	% mas.										
XRF/ICP-AES	54.26	16.80	9.81	3.54	6.38	1.73	3.64	2.17	0.91	0.14	99.44

Tab. 1: Chemical composition of diabase glass ICP – AES (Fig. 1)

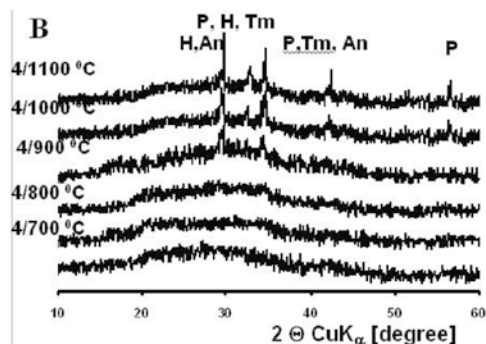
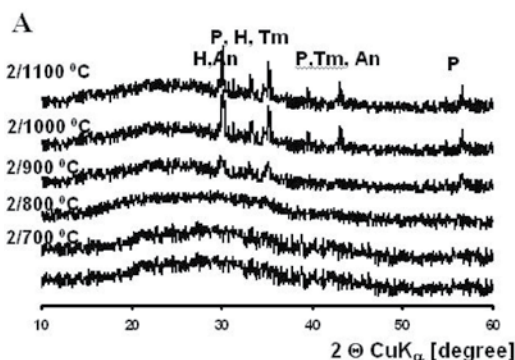


Fig. 2: XRD patterns of diabase glass from Niedzwiedzia Gówa melted in 1400°C and annealed in different temperatures for 2 and 4 hours. Abbreviations: H - hematite, An - anorthite, Tm - titanomagnetite, p - pyroxene

$$\Delta T = T_c - T_g \quad (1)$$

High value of thermal durability index $\Delta T = 251$, shows low crystallization ability of diabase glass. Such result is very advantageous in the aspect of exploiting fibers obtained from diabase.

The results of X-ray analysis confirmed low crystallization ability of glass. Diffraction lines coming from crystalline phases such as titanomagnetite, pyroxene represented by augite and hematite occur not before 900°C. The reflections are slight and wider which can be evidence of low order degree of examined glass. Further increase in temperature of diabase glass annealing 1000°C and 1100°C may result in distinct diffraction lines appearance, while extending annealing time from 2 to 4 hours leads only to slight increase in their intensity (Fig. 2).

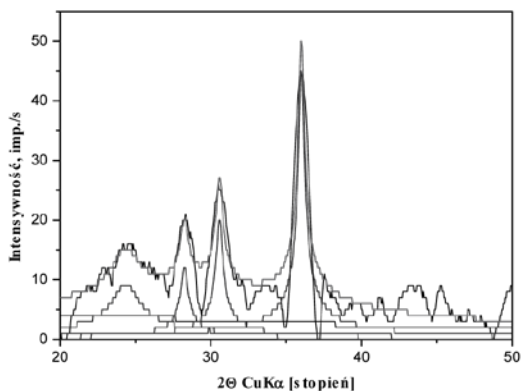


Fig. 3: Diabase diffraction pattern (DNG), annealed for 2 hours in 1100. Line used: ----- experimental curve; ----- adjust curve; refrections from crystalline phases and amorphous phase

Obtained diffraction curves (fig. 2) were also used for numeric analysis in order to estimate cristallization degree. Distribution of XRD paternns into diffraction reflections coming from cristalline phases and amorphous phase maximum was performed. Subsequently best matching curves were determined in relation to experimental curves.

Figure 3 shows curves distribution for diabase glass (DNG), annealing for 2 hours in 1100°C.

Acquired data was used to estimate angular positions of reflections ($x_i = 2\Theta$), their maximums and integral intensity (A_i). Crystalline phase content in analyzed glass was determined on the basis of sum quotient of integral crystalline reflections intensities to diffraction curves integral intensity [8]

$$Sk = \frac{\sum I_{kryst}}{K \cdot I_{amorf.} + \sum I_{kryst.}} \cdot 100\% \quad (2)$$

where:

Sk – crystallization degree

$\sum I_{kryst.}$ – integral intensities sum of radiation in crystalline areas

$I_{amorf.}$ – integral intensity of dispersed radiation in amorphous areas

K- proportionality coefficient

Estimation results of crystallization degree were compared with estimated values Sk, on the basis of glass density difference. To perform that,

glass density/thickness dependence in initial state was used, and after soaking/arching/firing - by equation 3 [3]. Obtained results are put in table 2. For comparison, previous research results are presented as well, concerning traditionally used basalt alloys.

$$Sk = 100\% \cdot \frac{\frac{1}{\rho_g} - \frac{1}{\rho_{gc}}}{\frac{1}{\rho_{gt}} - \frac{1}{\rho_c}} \quad (3)$$

where:

ρ_g – densities of initial glasses (experimental determinate)

ρ_{gc} – densities of glasses after the treatment (experimental determinate)

ρ_{gt} – densities of glasses, calculated using Appen's method [1]

ρ_c – densities of glass-ceramic crystal phases [6]

$$\frac{1}{\rho_{gt}} - \frac{1}{\rho_c} = 0,059; [3]$$

CONCLUSION

Obtained results give basis to conclusion that obtained diabase glass has low crystallization ability, which influences positively the durability of produced fibers. Estimated values of crystallization degree using X-ray method and density difference are comparable and show slight contribution of crystalline phases. For glass annealed in 900°C for 2 hours it is below 20%, whereas for traditionally used basalts the crystallization degree is ~40%.

Lp.	Glass	Initial state density	Density after annealing 2h/900°C	Crystallization degree, Sk, [%]	
		ρ_{gc} [g/cm ³]		Density method	XRD method
				2h/900°C	2h/900°C
1.	diabase	2.805	2.894	20	15
2.	basalt	2.835	3.042	41	42

Tab. 2: Glass density in initial state and after crystallization process with determinate crystallization degree (XRD method, density)

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