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NUMERICAL AND EXPERIMENTAL ANALYSIS OF COOLING PART IN QUENCHING OIL ISOMAX 166

NUMERICKÁ A EXPERIMENTÁLNA ANALÝZA OCHLADZOVANIA SÚČIASTKY V KALIACOM OLEJI ISOMAX 166

Abstract

The main aim of the article is computer modeling of transient temperature and stress-strain fields and experimental verification of the influence of residual stresses on the shape and dimensional changes of a quenched part. The modeled part with defined slot is cooled from the initial temperature of 850 °C in quenching oil ISOMAX 166 with steady-state temperature of 60 °C. Simulation model involves nonlinear thermo-physical and thermo-mechanical material properties of the part material DIN 1.4541. Thermal load of the part surface during cooling is modeled through convection heat transfer. The combined heat transfer coefficient is a function of surface temperature. The problem is solved by finite element method using the engineering-scientific program code ANSYS.

Abstrakt

Cieľom práce je počítačové modelovanie nestacionárnych teplotných a napäťovo-deformačných polí spojené s experimentálnym overením účinku zvyškových napätí na tvarové zmeny. Modelová súčiastka s definovanou drážkou je ohriata v peci na teplotu 850 °C a potom ochladená v pokojnom kaliacom oleji Isomax 166 s teplotou 60 °C. Simulačný model obsahuje nelineárne termofyzikálne a termomechanické vlastností materiálu súčiastky (DIN 1.4541). Tepelné zaťaženie povrchu súčiastky pri ochladzovaní je konvektívne s kombinovaným koeficientom prestupu tepla, ktorý je funkciou teploty povrchu. Úloha je spracovaná metódou konečných prvkov v inžiersko-vedeckom programovom súbore ANSYS.

1 INTRODUCTION

Qualitative change of material structure is obtained by heat treatment processes. Quenching is one of heat treatment processes, when rapidly cooling of part from quenching temperature in suitable cooling medium is needed. Knowledge of parameters of cooling medium and physical mechanical properties of part material allow predicting conduct cooling of part during cooling process. Actual trend in engineering approach in heat treatment is numerical simulation of transitional temperature fields and stress-strain states connected with body of quenched part. Aim of this paper is to verify substantiality rate of results of simulation model and real effect of cooling. Cooling medium was quenching oil ISOMAX 166 in unagitated state at temperature 60°C. Tested part was tube made of material DIN 1.4541 with outer diameter 42.5mm, wall thickness 3.25 mm and length 60 mm.

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2 TEORETICAL BASE

Thermal task. Sample temperature field is the result of energy transfer in form of heat at heating (necessary process before cooling) and consecutive cooling. Temperature fields are transient and they are described by Fourier- Kirchoff differential equation of heat convection for Cartesian coordinate system [1]. Tube material is considered as isotropic and thermo-mechanical properties are the functions of temperature (Fig. 3). Thermal load of tube presents 3rd type boundary conditions, i.e. heat transfer by convection [2]. It was used function dependency of combined heat transfer coefficient on tube surface temperature, which was quantified through INK method [3]. At heating heat transfer surfaces of tube were loaded by convective boundary conditions (Fig. 2) obtained by research on Institute of Production Systems and Applied Mechanics, Slovak University of Technology, Faculty of Materials Science and Technology in Trnava.

Structural task. As the result of temperature field, tube shape, coefficient of thermal expansion and material´s mechanical properties: elastic modulus, Poisson ratio (0.3) and yield stress is generation of stress-strain states in tube. Stress fields are described by equation for temperature stress state [4]. Thermo-mechanical properties of material are in Fig. 3. And were considered for thermal interval 20 to 900°C. Material model was elasto- plastic with bilinear isotropic strengthening (Fig. 4). Generation of plastic strains results from hypothesis HMH. Plastic strain grows up if Mises equivalent stress reaches the higher value like the yield stress R_e (characteristic stress) for given temperature [5]. Reference temperature for structural task was 20°C.

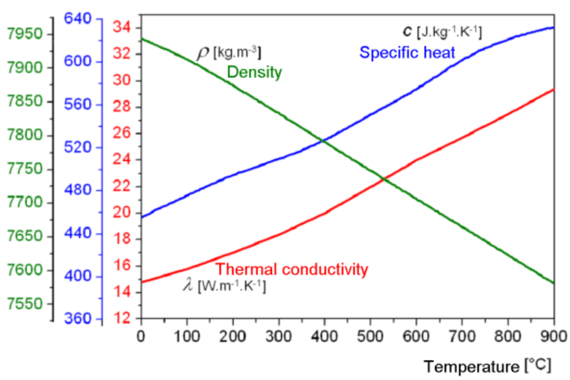


Fig. 1 Thermophysical material properties

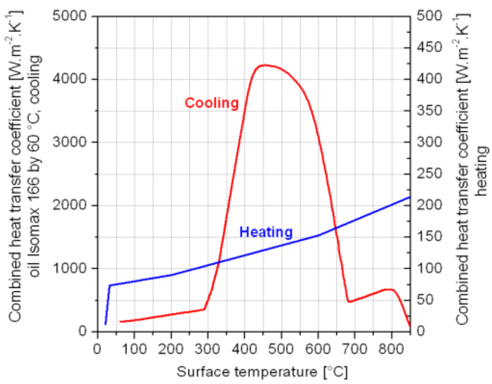


Fig. 2 Combined heat transfer coefficients

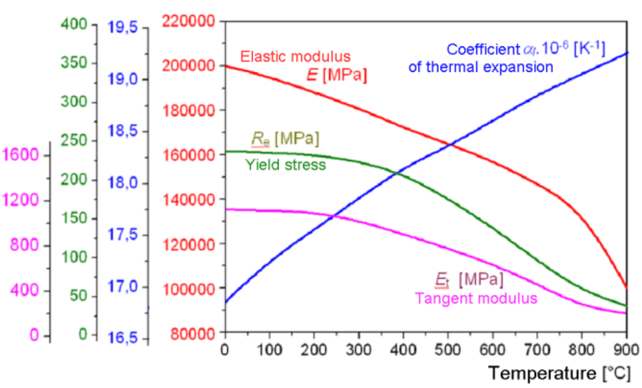


Fig. 3 Thermomechanical material properties

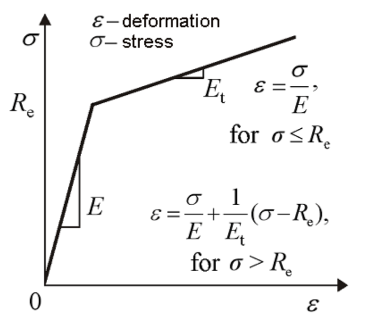


Fig. 4 Elastic-plastic material model

3 EXPERIMENT CONDITIONS

Temperature in muffle furnace LM 412.27 within heating was 850°C. Cooling was in unagitated quenching oil with steady-state temperature 60°C. Initial temperature of tube was 20°C. The time for heating was chosen as 600 s because of temperature equalization and material austeniziting condition. Cooling of the sample follow immediately after the end of heating. The time of cooling was 400s. It was created a video recording during cooling process (Fig. 7a). The slot width was the same heightwise and at the process beginning the width was 1.72 mm (Fig. 5)

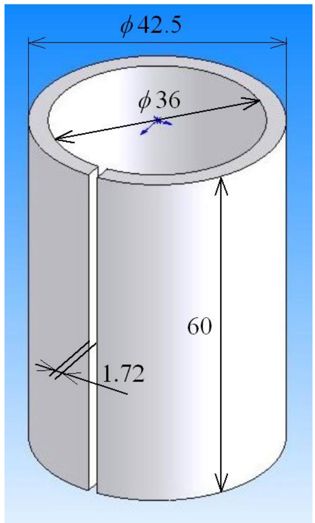


Fig. 5 Dimensions of sample

4 NUMERICAL SIMULATION

Geometric model and generated mesh were created for quarter of tube (Fig. 6). There were used symmetry conditions and model was griped at point 1 considering the displacement in direction of x axis. Element was the type Brick 186 with quadratic base function. Computing procedures were non-linear and transient. The task was solved using the engineering-scientific program code ANSYS.

5 OBTAINED RESULTS

Monitored result were temperature field, residual stress fields at selected time of cooling and slot width-time dependence during the whole process. Figure 7 shows comparison of temperature field in time 3.2 s after insert the sample to oil. The cooling process is captured on photography. Each of three types are evident: vapour blanked (A), boiling of oil (B), convection after ending of boiling (C). There is a reference temperature field from numerical simulation in Fig. 7b. For distribution of residual stress after heating end on temperature 60°C, see for Fig. 8. At the figure is evident that stress field during cooling reach and overreach the characteristic stress (yield stress). Consequences of existence of residual stress are distortion and thereby change of slot width. Time dependence of slot width can be seen in Fig. 9. The slot width was after cooling 1.43 mm. Maximum change of slot width was during cooling at phase of oil boiling.

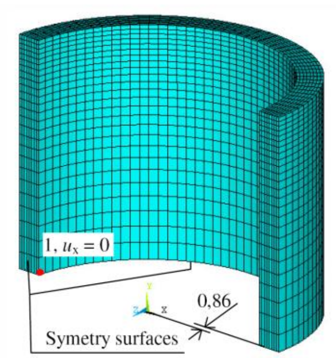
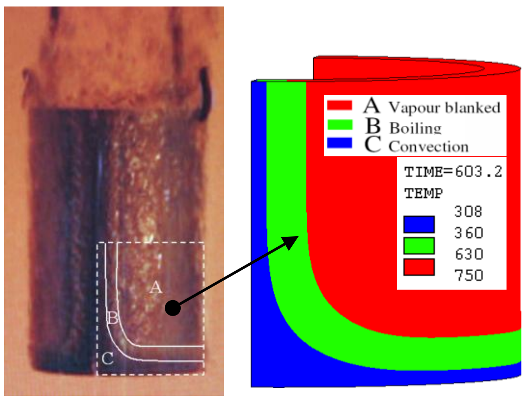


Fig. 6 Geometrical model with generated mesh



a) b)

Fig.7 Temperature field [°C], cooling time 3.2 s, a) photo, b) numerical simulation

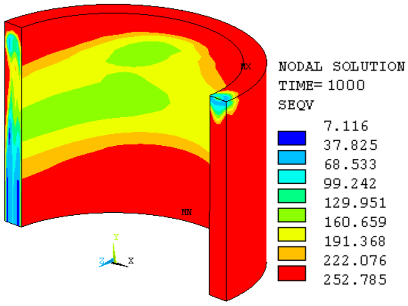


Fig. 8 Residual equivalent von Mises stress field [MPa]

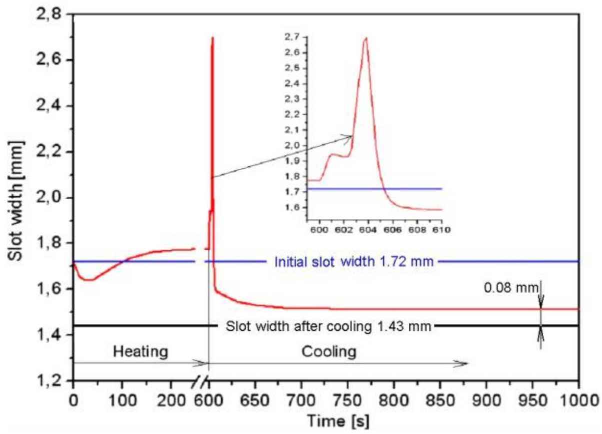


Fig. 9 Slot width time dependence

3 CONCLUSIONS

1) Connection between experiment and numerical simulation allow obtaining knowledge and better comprehending the dependence between parameters of heating process and cooling in quenching oil.
2) Loading boundary conditions of heating and cooling obtained by INK method were showed as sustainable. Their influence on process was confirmed by video record from cooling.
3) Influence of particular parameters on stress-strain state of cooling sample can be determined by indirect measurement method of slot width change.
4) Relative error between slot width after cooling obtained by experiment and by computation way was 5.6%.
5) The greatest influence of parameters solved structural task on slot width change has linear coefficient of thermal expansion of used material.

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