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# The Methodology for Determination of Optimal Warm Forging Temperature using Computer Simulation

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**Abstract.** Warm forming is most commonly used in production of die forgings manufactured by precise forging. As compared with cold forming, using warm forging we are able to reduce size of forging forces considerably. The development of forging technology is connected to research of forgeability and plasticity of formed material at warm temperatures. The contribution brings a description of methodology used for determination of optimal forging temperature from recommended warm temperature interval concerning the chromium - manganic steel 16MnCr5. The mentioned steel is applicable for case hardening and manufacture of precise die forgings. In order to verify the steel forgeability within the recommended warm forging temperatures interval 600, 650, 700 a 750 °C the upsetting test according to Židek was used. The computer simulation of technologic test by means of program MSC.SuperForge confirmed correct selection of warm temperatures because testing samples showed good formability and after pressing in a notch area no cracks or defects were revealed. The crucial plasticity factor for selection of optimal warm temperature from examined temperature interval was a value of reduction of area determined by tensile test.

**Keywords:** Warm Forming, Warm Temperature, Plasticity, Forgeability, Pressure test, Simulation

## Introduction

Compared to standard hot forging, by warm forging higher exploitation of material, higher quality of surface and also dimensional precision of forgings is reached. For the purpose of warm forming it is important to determine an optimal upper forging temperature since the recommended temperature interval is quite narrow [1,2,3]. Consequently, there arises a chance that when the recommended temperature interval is not kept the material can be easily brought to the area of brittleness. In order to obtain a fine-grained structure and good mechanical properties of forgings it is important to bring the temperature of finishing forging near to the recrystallization temperature. Important is especially the dependence between forming temperature and ductility of material [4,5]. For the development of warm forging technologies it is reasonable to consider the influence of the temperature on mechanical properties and plasticity indexes concerning the specific type of steel.

## Setting the interval of warm forging temperatures for tested material

The research of plasticity in the temperatures of warm forging was performed on 16MnCr5 steel alloy. It is chromium-manganic construction steel, suitable for case hardening, which has appropriate warm ductility, after spheroid zing also the cold ductility. It is used for production of case hardened machine parts with very hard surface and after quenching also with high rigidity of core. This kind of steel is suitable for precision die forging according to its chemical composition and mechanical properties.

For low carbon steels the temperatures of warm forging higher than recrystallization temperature $T_{rek}$ but lower than structure change temperature $A_{c1}$ are recommended. Therefore is it necessary to set up the temperatures $A_{c1}$ and $T_{rek}$ for examined steel and consequently set up the temperatures for upset test within the pre-set interval.

**Table 1:** Chemical composition of steel 16MnCr5 (wt%)

| Element | C | Mn | Si | Cr | Ni | Mo | W | P | S |
|---|---|---|---|---|---|---|---|---|---|
| Composition | 0,165 | 1,321 | 0,253 | 0,9 | 0,139 | 0,043 | 0,022 | 0,011 | 0,015 |

Tin order to set up the temperatures $T_{Ac1}$ and $T_{rek}$ it is necessary to know exact steel alloy 16MnCr5 components percentage. The values were indemnified by optical emission spectroscopy according to table1. The recrystallization temperature $T_{rek}$, melting

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temperature $T_{tav}$ and structure change $T_{Ac1}$ temperature were calculated as follow [6].

$$T_{rek} = 0{,}4.T_{tav} \quad [°C] \qquad (1)$$

when: $T_{tav}$ – melting temperature

$$T_{tav} = 1537 - (88C + 8Si + 5Mn + 5Cu + 1{,}5Cr + 4Ni + 2Mo + 2V + 30P + 25S) \quad [°C] \qquad (2)$$

$$T_{Ac1} = 723 - 10{,}7\ Mn - 16{,}9\ Ni + 29{,}1\ Si + 16{,}9\ Cr + 290\ As + 6{,}38\ W \quad [°C] \qquad (3)$$

For steel 16MnCr5 is valid: $T_{rek} = 604$ °C $A_{c1} = 729$ °C

Based upon calculated values of temperatures $T_{Ac1}$ and $T_{rek}$ the temperature interval for warm forging of 16MnCr5 steel was set up at values from 600 to 750 degrees of Celsius.

**Research of 16MnCr5 steel forgeability at recommended temperature interval**

For the verification of steel forgeability by warm forging, the technological test of upsetting according to Židek is used. The test is based upon deformation of cylindrical test sample with four notches while given temperatures are employed [7,8,9]. Samples with diameters of Ø30 x 40 mm are deformed by one third of their height. The presence of cracks in notches is evaluated.

The test author Žídek recommends five classification degrees used for forgeability evaluation according to appearance of cracks in cylinder notches:

- 1 – without cracks (good forgeability)
- 2 – small separated cracks (lowered forgeability)
- 3 – small cracks in all notches (medium lowered forgeability)
- 4 – medium cracks in all notches (downgraded forgeability)
- 5 – big cracks (fractures) in all notches

Warm forgeability of steel is considered by mean value, which is given by classification level according to examined temperatures.

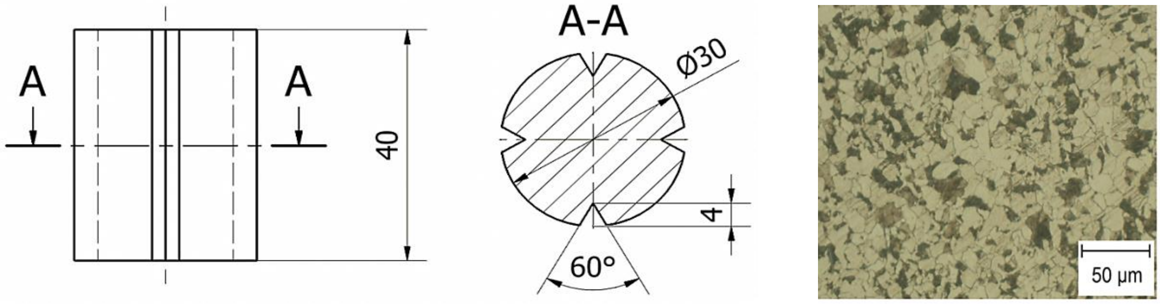


**Fig. 1** Shape and dimension of test sample

Testing samples were made from a bar heat rolled, which was provided without any heat treatment. In order to harmonize mechanical properties and obtain fine-grained structure it was necessary to anneal the testing cylinders. The shape and dimension of a test sample and initial microstructure are shown in Fig. 1.

The pressure tests were performed at set temperatures 600, 650, 700 a 750 °C, whereas three testing samples were examined at each temperature. The cylinders with notches were upset on vertical forging machine LZK 1600 by one third of its height and the appearance of cracks in notches was evaluated. Accordingly the appearance of cracks in notches pursuant to classification degrees at particular temperatures was evaluated - the results are stated in Table 2.

**Table 2** Evaluation of cracks in notches of the test sample

| Temperature [°C] | 600 | 650 | 700 | 750 |
|---|---|---|---|---|
| Classification degree | 1 | 1 | 1 | 2 |

Before executing the laboratory experiment a computer simulation of technologic test was performed by means of program MSC.SuperForge. The simulation confirmed correct selection of warm temperatures, because testing samples showed good formability and after pressing in notch area no defects or cracks were revealed. Example of a cylinder pressed during the experiment and simulation of upsetting process is shown on Fig. 2 and Fig.3.


**Fig. 2** Shape of deformed test sample at temperature700 °C
a) laboratory experiment b) computer simulation

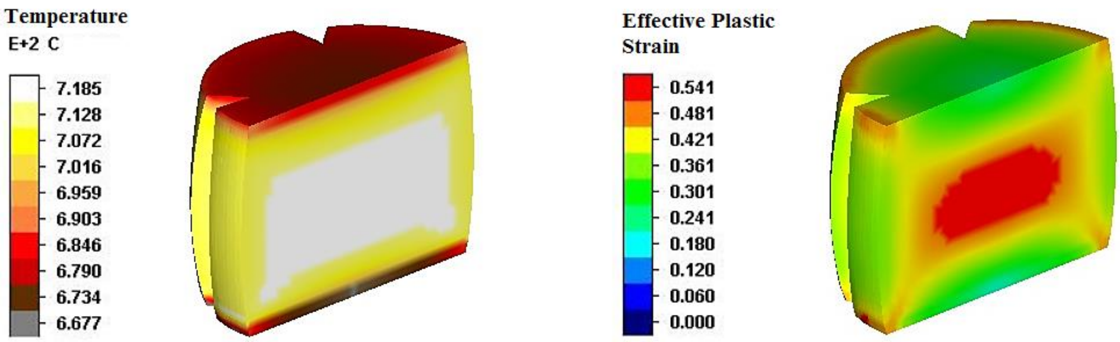


**Fig. 3:** Simulation of temperature distribution, effective transformation when the temperature of upsetting was 700 °C

Forgeability of low-carbon steel 16MnCr5 in warm temperatures interval was evaluated on the basis of mean value concerning classification degrees for particular temperatures. Reached value 1 means good formability of 16MnCr5 steel at warm conditions with regard to temperatures 600, 650 and 700°C. Sporadic cracks in notches appeared at testing temperature 750°C. The mentioned temperature is not recommended as upper forging temperature.

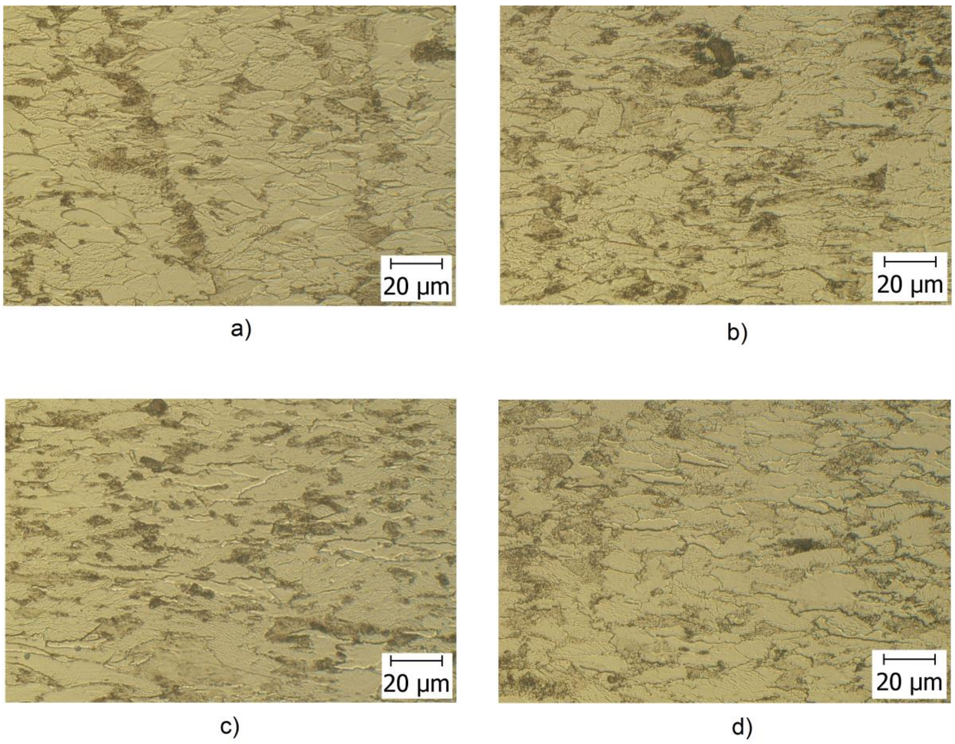


**Fig. 4** Microstructure of steel 14220.1 after finishing the test according to Židek at set temperatures a) 600 °C, b) 650 °C, c) 700 °C, d) 750 °C

Fig. 4 characterizes the 16MnCr5 steel microstructure after application of pressure test at set temperatures. On the samples we are able to observe a ferrite – perlite structure, whereby a grain deformation along pressing of testing samples is visible / evident. At the temperature of 700 C arises a spherical/ globular perlite which consists of cementite parts that have positive effect on formability.

**Selection of optimal forging temperature from warm temperature interval**

In order to consider the temperature influence on plasticity and workability of examined steel 16MnCr5 within the scope of recommended warm forging temperature interval the tensile test was applied at increased temperature according to STN EN 10002-5 [7,9]. Testing cylinder bars were made out of a circle bar hot rolled and later annealed. For the purpose of test execution the testing machine LabTest with maximum loading force 250 kN was used. The machine includes a small electric furnace with heating up to 1000 °C.

The tensile test was performed at set temperatures 600, 650, 700 a 750 °C. After executing a static test, dimensions of testing bars were measured and using a calculation the basic characteristics of plasticity (reduction of area Z, and ductility A) and indicators of workability at increased temperatures were defined as follows:

Index of plasticity according to Kolmogorov: $\lambda_R = 2.\sqrt{3}.\ln\frac{d_0}{d_u}$ [-] (4)

where $d_o$ – initial diameter [mm], $d_u$ – minimal diameter in rupture point of the sample [mm]

Paur´s index of forming capacity: $D_{sm} = \frac{1}{1-Z} - 1$ (5)

Here applies: $Z = \frac{S_0 - S_u}{S_0} < 1$

where $S_o$ – initial area [mm$^2$], $S_u$ – minimal area in rupture point of the sample [mm$^2$]

Yield strength – tensile strength ratio : $\frac{R_e}{R_m} < 0{,}7$ (6)

The graphic relations displayed in fig. 5 were designed pursuant to average values of calculated parameters resulted from the tensile test. The course of strength characteristics $R_m$ and $R_{p0,2}$ of examined steel proves declining tendency depending on increasing temperature. On the basis of thermal course of plasticity characteristics (reduction of area Z, ductility A) we are able to observe reduction of area decline at the temperature 750 °C. At the mentioned temperature the plasticity decreased and it is not possible to recommend the same as upper forging temperature.

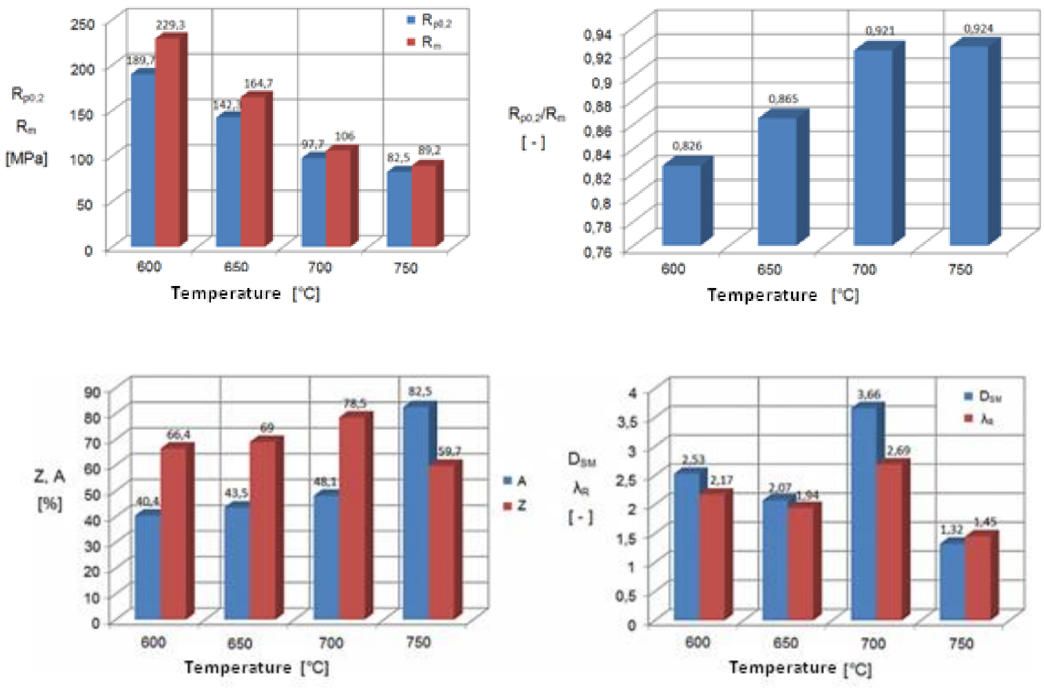


**Fig. 5** Courses of graphic relations of parameters resulted from the tensile test

For the purpose of optimal warm temperature selection from examined temperature interval the crucial indicator of steel 16MnCr5 plasticity is value of reduction of area Z. This plasticity characteristic provides reliable results comparable to production practice. As reduction of area Z achieves its maximum value at the temperature 700 °C, the same will be recommended as optimal temperature of steel 16MnCr5 for warm forming. Furthermore, the factors of forgeability $D_{sm}$ and $\lambda_R$ reached maximum values at the temperature 700 °C as well.

## Summary

The technology of warm forging brings considerable economic profit through material and energy savings. Economy of mentioned technology is mostly influenced by correctly selected interval of warm temperatures [1,10]. The method used for determining of temperature interval for warm forging, which is described in this contribution, is applicable to various types of structural steels. Furthermore, basic tensile test at increased temperatures as well as pressure test by Zidek used for forgeability determination are appropriate also for research of non-ferrous metals, especially for Al and Mg alloys. For further development of warm forging technology it is necessary to focus on research of temperatures influence on material plasticity.


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