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INFLUENCE OF TEMPERATURE ON PLASTICITY AND WORKABILITY OF ALUMINIUM ALLOYS

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ABSTRACT: *Applications of aluminium alloys for drop forgings production are permanently increasing especially in the automotive industry. Alloys AlCuMg type have an significant position due to their low density compared to structural steels. This contribution provides information about mechanical properties, plasticity and workability of aluminium alloy AlCu4Mg1 at hot forming temperatures and at recovery temperatures. Database and comparison of measured values is important for future development of warm forming. Warm forging of drop forgings represents a lucrative method of precise forgings production not only from the energy and time savings point of view, but also for obtaining of higher surface quality and dimension precision of forged pieces too.*
KEYWORDS: *plasticity, workability, hot forging, warm forming, strain hardening index, numeric simulation*

INTRODUCTION

Temperature is an important argument for testing of metals in conventional conditions. Plastic deformation is realized during cold forming of metals by slip and material is strain hardened.

Warm forming passes with partial strain hardening of metal above recovery temperature and below temperature of recrystallization [1]. Recovery removes microscopic and macroscopic stresses while physical and partly plastic properties of metal improve. Values of tensile strength and yield point decrease and formability increase [2].

Hot forming passes at temperatures over temperature of recrystallization. Simultaneously with metal forming processes a primary recrystallization passes and due to repeated replacing deformed grains by new set undeformed grains the strain is unlimited.

Plastic properties of metals are not considered as linear function of temperature, therefore it is necessary at hot bulk forming and warm bulk forming to accurately determine an appropriate interval of forming temperatures [2, 3].

EXPERIMENTAL MATERIAL AND MEASUREMENT

The subject of workability research at increased temperatures is aluminum alloy A2024 - STN 42 4203.61 (natural ageing), chemical specification AlCu4Mg1. This alloy, which belongs to the group "2000" of aluminum alloys, has a main alloying element Copper. Chemical composition of used alloy is in Table 1.

Table 1. Chemical composition of Al alloy (% weight)

Cu	Mg	Mn	Fe	Si	Zn	Ti	Ni	Al
min. 3.8 max. 4.8	min. 1.2 max. 1.8	min. 0.4 max. 1.1	max. 0.5	max. 0.5	max. 0.2	max. 0.2	0.1	bal.

Alloy AlCu4Mg1 (duralumin) is an age-hardenable alloy determined primarily for hot forming at temperature interval 340-450 °C. This alloy is characterized by high tensile strength, which comes up to 470 MPa after hardening and it is possible to be increased by forming. Corrosion resistant of this alloy is relatively low. Alloy is widely applicable in automotive and aviation industry in production of various structural elements. Suitability of examined alloy for warm bulk forming was considered by tensile test at higher temperatures.

Cylindrical bar tensile test specimens were used. The gage length L_o was 60mm, diameter d_o was 8mm. The specimens were tested at room temperature and at temperatures 150, 200, 250, 350, 400 and 450°C. These temperatures represent a temperature interval of warm forming of aluminum alloy and hot forming temperatures (recommended hot forming temperature interval is from 350 to 450°C).

EXPERIMENTAL RESULTS

Strength limit R_m, characteristics of plasticity for workability at higher temperature (reduction of area Z, index of plasticity to rupture according to Kolmogorov λ_R, Paur's index of plasticity D_{sm}) and exponent of strain hardness were calculated from measured results on three tested specimen at each *tested temperatures. Index of plasticity to rupture according to Kolmogorov λ_R was calculated according equation (1), where d_o is original diameter of test specimen, d_u is diameter of specimen in failure place, Paur's index of plasticity D_{sm} was calculated according equation (2), where Z is reduction of cross sectional area. Exponent of strain hardness n was determined as true plastic strain at tensile strength point where plastic deformation stability is lost.*

$$\lambda_R = 2\sqrt{3}\ln\frac{d_o}{d_u} \tag{1}$$

$$D_{sm} = \frac{1}{1-Z} - 1 \tag{2}$$

Temperature course of tensile strength is in Figure 1, temperature course of percentage reduction of area Z is in Figure 2, temperature course of index of plasticity according to Kolmogorov λ_R is in Figure 4, Paur's index of forming capacity D_{sm} is in Figure 3.

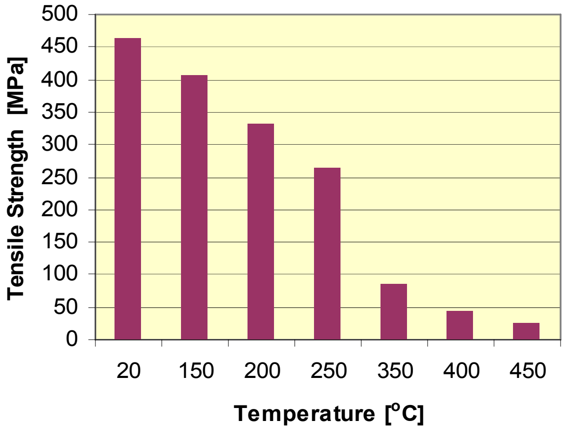

Figure 1. Temperature course of tensile strength

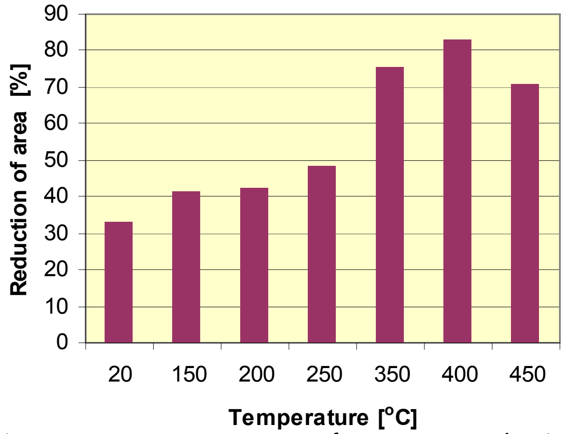

Figure 2. Temperature course of percentage reduction of area

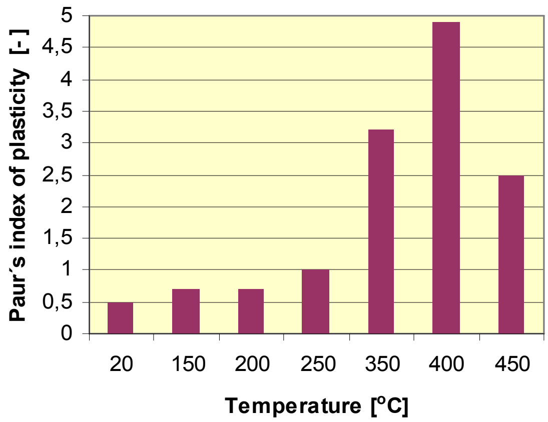

Figure 3. Temperature course of Paur's index of forming capacity

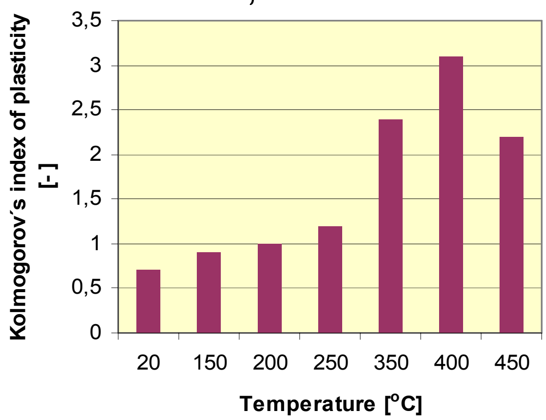

Figure 4. Temperature course index of plasticity according Kolmogorov

Based on the results it is obvious that tensile strength decreased and on the other hand the value of percentage reduction of area increased. Plastic properties at warm temperatures were increased as it is shown by percentage reduction of area, which value at temperature 250 °C was 1.5 times higher then its value at room temperature. This fact suggests grow of material plastic properties in warm conditions. Index of plasticity according to Kolmogorov and Paur's index of plasticity have similar course as reduction of area and it proves increase of plasticity in dependence on temperature as well. Highest growth of plastic properties of Al alloys is at hot forming temperatures 400°C.

It can be seen, that the material set lower strain resistant with increasing temperature and the area of equilibrium plastic deformation decreased. The great differences between values of strain hardening index at 250°C and 260°C (additional analyzed temperatures) evidences, that 250°C is limited recrystallization temperature of alloy, range of plastic deformation rapidly decreased. Its value upper 260°C is very low. Determined values of strain hardening index are in Table 2.

Table 2. Values of strain hardening index n at warm temperatures

T [°C]	200	240	250	260
n	0.071	0.062	0.042	0.011

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NUMERIC SIMULATION OF PROCESS

Research of workability of alloy AlCu4Mg1 is important for users of simulation software in term of spreading of material databases and optional of simulation parameters of different forming technologies, e.g. forging, metal spinning, drawing etc. Simulation software is necessary for simulation of material flow in forming tool [4]. This software enables arrangement of tools still in the preparation stage and thus saves production costs [5, 6] and quality of work pieces by technology process optimization [7].

For the development of war forging technologies it is important to have knowledge about behaviour of the material at reduced mechanical working temperatures. On the basis of experimental results an optimal warm forging temperature for the alloy AlCu4Mg1 was recommended 250°C, an optimal hot forging temperature 400°C.

Crank press LZK 1000
Upper Die – Model upper die
Material: DB.H-13 (A579 - STN 41 9552)
Friction: 0,1
Die temperature: 150°C

WorkPiece – Model Billet:
CYLINDER Ø40x24mm
Material: DB.AA 2024 (STN 42 4203)
Workpiece temperature: 250°C, 400°C

Lower Die – Model lower die
Material: DB.H-13 (A579 - STN 41 9552)
Friction: 0,1
Die temperature: 150°C

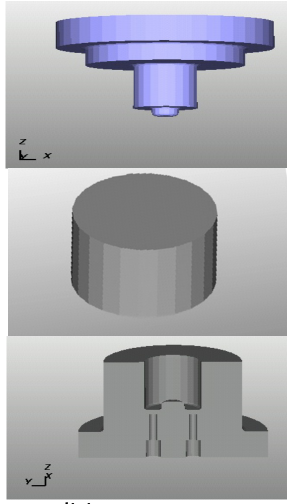

Figure 5. Input simulation conditions

An example of numeric simulation of plastic flow at temperature 250 °C was applied to forging of drop forging in closed die. Big aid pro production practice is comparison of plastic flow, courses tension, deformation, temperatures and force at standard forging temperature 400°C and war forming temperature 250°C.

Defined input conditions for simulation of forging process of drop forging with ring shape in simulation Programme MSC SuperForge are in Figure 5, results of simulation are in Figure 6.

Shape of the drop forging was the same at both temperatures – material flow was very good (see Figure 6b, 6i), the drop forging was without any folds and surface defects. Effective stress (Figure 6c, 6j), contact pressure (Figure 6d, 6k) and forging force (Figure 6e, 6l) at warm temperature (Figure 6c, 6d, 6e) were about two times greater then at hot temperature (Figure 6j, 6k, 6l). Based on the results (Figure 6a) it is obvious that at warm forging temperature rapidly increased at final shape forging.

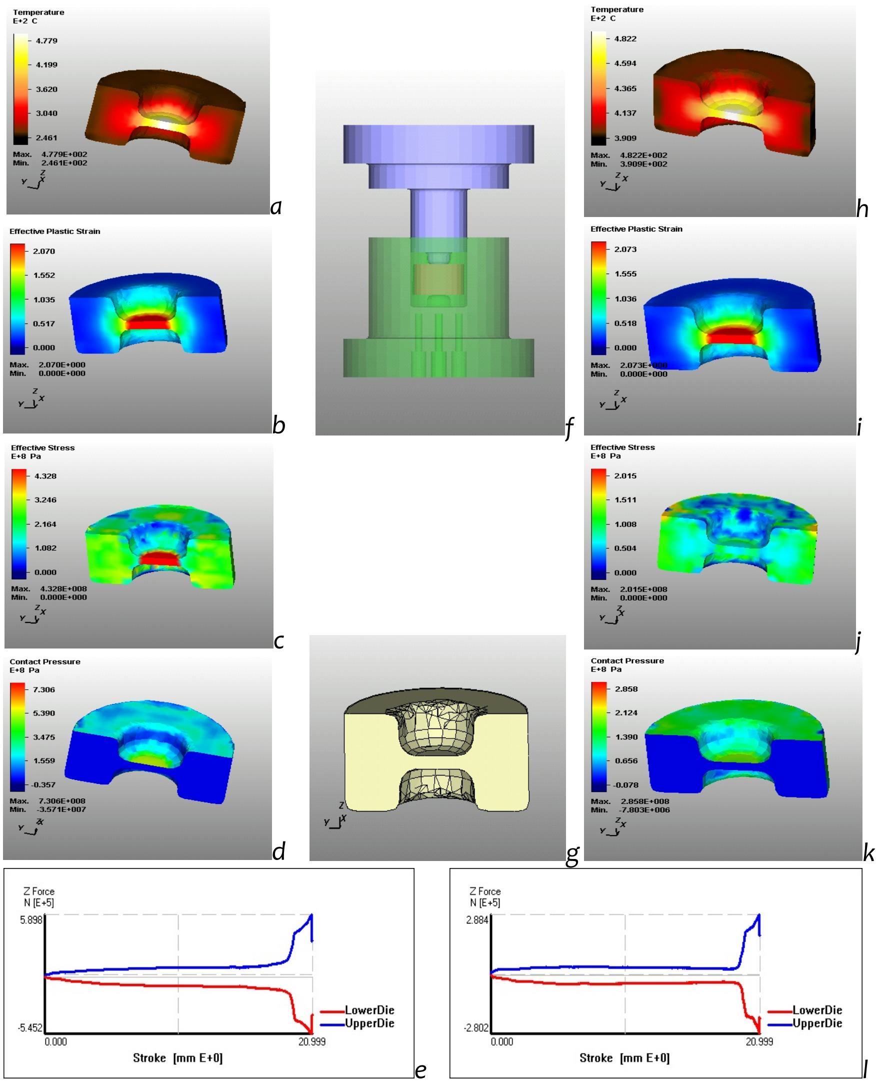

Figure 6. Numeric simulation of forging process in closed die (f, g) at warm temperature (a to e) and at hot temperature (h to l) (Simulation software MSC.SuperForge)

DISCUSSION OF RESULTS

Tensile strength decreased and on the other hand the value of percentage reduction of area increased with increasing temperature. The best plastic properties of Al alloys are at 400°C. On the basis of the experimental results an optimal hot forging temperature is 400°C. From the analysis of plastic properties (index of plasticity according to Kolmogorov, Paur's index of plasticity and reduction of area it can be seen, that at temperature 250°C they were about 1,5 times higher then its value at room temperature. From the values of strain hardening index we can see, that area of equilibrium plastic deformation decreased. There are great differences between values of strain hardening index at 250°C and 260°C (additional analyzed temperatures) and its value upper 260°C is very low. From these result an optimal warm forging temperature for the alloy AlCu4Mg1 was recommended 250°C.

Numeric simulation of forging process at warm temperature 250°C with comparison of numeric simulation of forging process at hot temperature 400°C showed very good material flow and about two times greater stress, contact pressure and forging force. In case of applying this technology – warm forging at 250°C to small and medium drop forgings the forces and stresses have acceptable value.

CONCLUSIONS

On the basis of mentioned results it is possible to apply the technology of warm forging. The results of numeric simulation confirm that the choice of the temperature at warm forging was good. Material flow was very good, but mechanical load of tool was relative high, maximum temperature of drop forging was relative high too. It leads to higher requirements on forging tool design. Therefore to production technology it is possible to apply the technology of warm forging to small and medium drop forgings with simple and not rugged shapes, when the forces are not extremely high. Before forging of workpiece at 250°C it is necessary to heat dies at temperature 150 °C because small drop forgings get cold quickly [8]. Thus this process prevents significant decrease of temperature while heated workpiece is in contact with tool and required higher plastic properties of material are provided. Lower temperature at warm forging in compare to hot forging can lead to saving of thermal power and enough lifetimes of dies too [9, 10].

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