PHYSICAL AND NUMERICAL SIMULATION OF FORGING OF Cu-Cr ALLOY

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1. Introduction

Development of the hot forging technology for copper alloys, which are characterized by high mechanical properties, is a goal of research in several laboratories. Repeatability of properties is the advantage of these alloys. Cu-Cr alloys are characterized by particularly high exploitation properties for a variety of applications combined with dependence of electrical conductivity on applied heat treatment. Various methods of thermomechanical processes are possible for this alloy and quite different properties are obtained depending on the parameters of this process. Thus, the technology design for Cu-Cr forgings has to combine obtaining required shape with control of microstructure and properties. The technology design is usually supported by physical and numerical simulations. This work is focused on application of both kinds of simulations.

2. Rheological model

Accuracy of numerical simulations depends on the correctness of description of boundary conditions and material properties. The latter problem is considered in this work. Although the rheological models are well explored for various steels, there is still lack of models for copper alloys. Thus, the prime objective of this work is performing uniaxial compression tests for the Cu-Cr alloy at temperatures 500-1000^{o}C and strain rates 0.1-100 s^{-1}, application of the inverse analysis [1] to the interpretation of results of those tests and development of the rheological model for the applicable for the investigated range of parameters. Three states of the alloy, yielding different mechanical response during deformation, were considered. A) samples after super saturation annealing at 1000^{o}C; B,C) samples after hot extrusion, followed by different preheating processes: B) heating to the test temperature, maintaining for 120 s and deformation; C) heating to 950^{o}C, maintaining for 300 s, cooling to the test temperature, maintaining for 60 s and deformation. Inverse analysis yielded the flow stress independent of the influence of such disturbances as friction or deformation heating for all investigated cases. Analysis of results showed [2] that oscillations in the material response occur for low Zener-Hollomon parameters for samples B and C.

Microstructure of the samples was investigated prior to deformation and after each test. Correlation between flow stress and microstructure was determined, see selected results in Fig. 1. Investigation of the deformed samples has shown that their structure depends strongly on the initial state of the material. Under the same deformation conditions, as extruded samples heated to the test temperature were subject to dynamic recrystallization (DRX) during deformation. Their structure was fully recrystallized with finer grains while lowering deformation temperature and increasing strain rate. In the other specimens, the DRX was not easily initiated during deformation below 900^{o}C and their microstructure was partly recrystallized. The solute drag effect of Cr atoms exerted on the recrystallization nuclei boundaries is a possible reason of different behaviour of the samples. Chromium effect on the stacking fault energy is an alternative reason. In the extruded samples all chromium precipitated out of the solution. The precipitates were relatively large and they did not affect the recrystallization process substantially. Thus, the super-saturated samples exhibit the greatest effect of Cr on the recrystallization. Samples reheated to 950^{o}C prior the deformation show the intermediate effect, and the effect of Cr is almost negligible in the extruded samples. Flow stress models accounting for the microstructure were determined using inverse analysis.

3. Modelling industrial forging process

FE code with the developed flow stress model was used for simulation and analysis of the industrial forging with following parameters: stock diameter 60 mm, mass of the forging 1.2 kg and die 2000 kg, initial temperature 900°C, die energy 70 kJ, die displacement 850 mm, die velocity 5 m/s. View of the die and the preform is shown in Fig. 2. Various variants of the process were considered. Selected results for the material after extrusion (variant B) only are discussed below. One example showing how simulation allows to eliminate faults is presented.

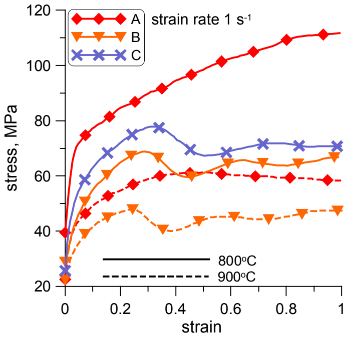

Figure 1. Flow stress for different initial state of the samples.

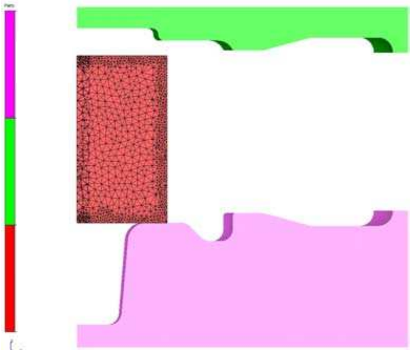

Figure 2. View of the die and the preform.

Simulation of the one stage closed die forging has shown that fault occurs at the surface. Therefore, upsetting is performed first and is followed by the forging. Three reductions in upsetting (10, 15 and 20 mm) are considered. Forging after upsetting with 10 mm reduction resulted in fault of the product (Figure 3a). Under filling of the die was obtained when 20 mm reduction was applied in upsetting (Figure 3c). Proper forging was obtained for 15 mm reduction in upsetting (Figure 3b).

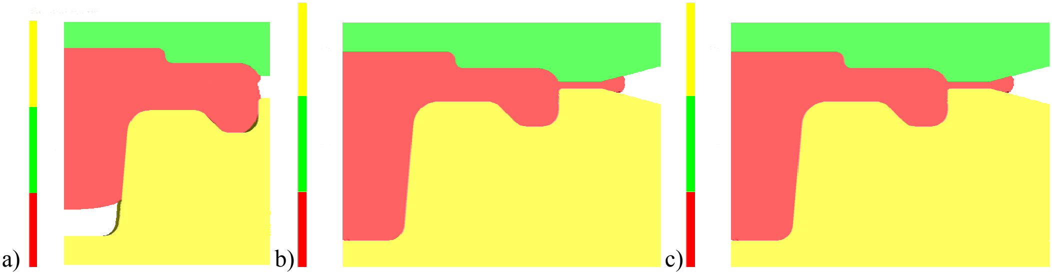

Figure 3. Die filling for various reductions in upsetting: a), 10 mm, b) 15 mm, c) 20 mm.

4. Conclusions

Rheological model of the CuCr alloy accounting for the state of microstructure was developed. Various variants of the industrial forging were simulated and the capability of the model to support technology is shown. 15 mm reduction in upsetting before forging is selected in the considered case as giving the best quality of the forging.

5. References

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[2] M. Pietrzyk, R. Kuziak. Model reologiczny miedzi chromowej w procesach obróbki plastycznej na gorąco, *Obróbka Plastyczna Metali*, **19**, 2008, in press.