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APPLICATION OF QFORM FORGING SIMULATION SYSTEM FOR PREDICTION OF MICROSTRUCTURE OF ALUMINUM FORGED PARTS

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Abstract

The development of numerical simulation of technological processes such as forging and heat treatment allows to optimize the technology including the product's mechanical properties. As an example the aluminum wheel forging was analyzed with the use of Ziner-Holomon's parameter. The investigations were performed for the most critical zones of the forged parts such as web, crown, upper and lower flanges. The information provided by QForm simulation system allows to control the strain-rate and to reach the required level of mechanical properties and to avoid undesired microstructure when forging the wheels from AB aluminum alloy.

Key words: aluminum forging, numerical simulation, structure, QForm3D

1. INTRODUCTION

Forged car wheels produced from light and strong aluminum alloys is the integral part of modern transport technique. One of the problems facing the industry is providing high level of the product's mechanical properties together with high-volume output development. The combination of the strain, the strain-rate and the temperature and the heat treatment conditions are responsible for the forming of the metal structure. The purpose of the present work is the development of the method of applying of the results of simulation provided by QForm program, such as the temperature fields, strain rate and strain for prediction of structure microstructure of within the forged part.

2. INVESTIGATIONS PROCEDURE

The developed method for workpiece structure prediction includes the following stages. At the first stage the forging process was simulated by QForm system (see Biba et. al, 2004) to analyze the strain, the temperature and the strain-rate distribution through the forged part volume. Then the parameter proportional to the accumulated energy is calculated and the critical zones in the forged part are defined. At the final stage of the investigation the ways to avoid the post-critical values of the stored energy are determined and improved forging technology are checked by simulation.

Recrystallization provides the greatest effect to the structure of hot-deformed metal. Depending on the stage of the process there are dynamic recrystallization that develops during deformation, static recrystallization that develops during heating of deformed metal and spontaneous recrystallization that takes place directly after finishing of hot metal forming (Weinblat, 1982). During hot metal forming the accumulated energy and the resulted structure condition depend not only on the strain but also on

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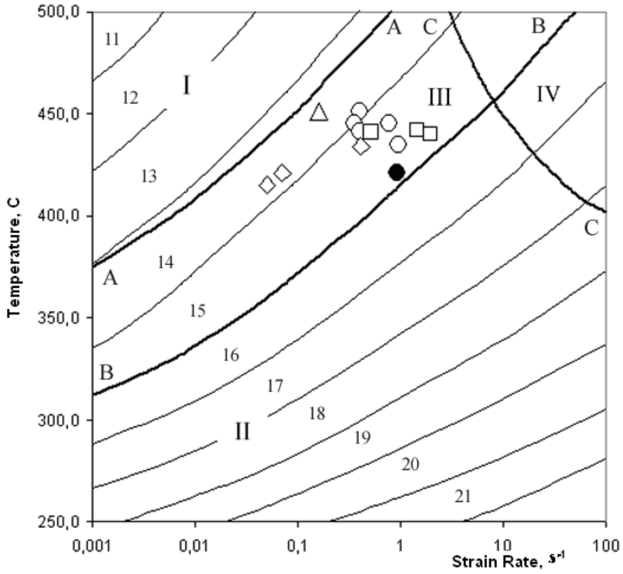
the temperature and the strain-rate. In this case it is better to use Ziner-Holomon's parameter (Z) as the measure of accumulated energy. This parameter is the criterion of joint influence of all parameters on the flow stress and in indirect way on the formed microstructure (Archakova, 1984):

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right) \qquad (1)$$

where: Q – activation energy of plastic deformation, R – gas constant.

In the work of Weinblat (1992) this parameter was used to construct diagrams of deformation mechanisms of aluminum and its alloys which finally determine the structural condition of semi-finished products directly after realization of technological actions. However for heat-treatable aluminum alloys it's important to know the structure not only after plastic deformation, but also after heating up to quenching temperature which can be lower or upper of the temperature at the beginning of recrystallization. Depending on this polygonal or recrystallization structure develops in deformed and heat-treated product. In this case the diagram of deformation mechanisms can be used as a structural condition diagram (figure 1) constructed in "strain rate – temperature of deformation" coordinates, as it was done for AB alloy by Novikov (1978).



● – *upper flange*

Fig. 1. *The diagram of structural state of AB alloy, deformed up to 50% and heated for quenching up to 520°C. The numbers near the curves are the values of lg Z [5].*

The line AA on the diagram separates the hot deformation zone I, where recrystallization does not occur during the heating for quenching. This line features the relation of two critical hot deformation parameters – the critical strain-rate and the critical temperature of deformation — and is called the line of critical conditions (Novikov,1978). The level of accumulated energy in the metal deformed in conditions that are higher of this line is not enough for recrystallization process during heating for quenching. The zone III of partial recrystallization is located between the lines AA and BB, and the structure of the deformed and tempered metal in this area will be mixed. Exactly this area is the most dangerous one because of irregular structure roughening and due to deterioration of mechanical properties as the result. The largest grains appear in the middle of the partial recrystallization zone when their growth is relatively free and is not constrained. Due to the large propagation of this zone (lg Z = 13-15) the critical value of lg Z corresponding to the beginning of structure roughening requires accurate definition by means of experiments.

The investigation of macrostructure of the samples from AB alloy [2] which were deformed in the temperature-strain rate conditions of the area III and heated to the temperature of quenching 520°C (figure 2), shows that the critical parameter for recrystallization during heating is the value lg Z = 14 that corresponds to the strain-rate 0.05 - 0.12 s^{-1} and the temperature about 420°C).

As far as the deformation temperature drops below 430°C the first areas with the recrystallized structure appear. They are seen at the deformation temperature 415°C (figure 2b). The further temperature decreasing leads to the growth of volume ratio of the recrystallized grains. In this case these grains are located within the specific cross like area in the upset workpiece meridian cross section (figure 2c).

The majority of technological forging processes for complicated parts like, for example, the wheels have several forging operations (figure 3). Theoretically every action contributes to the level of the accumulated energy in the metal structure. In practice cooling down of the workpiece due to contact with air and the dies also significantly effects the temperature of the deformation.

The forming operation ends when the value of lg Z becomes significantly greater than it was at the beginning. This let us to use just the final stage of forging for analysis of structure forming conditions. The source data for such analysis (temperature and strain-rate fields during deformation) are obtained by means of simulation by QForm using the tracked points to record the parameters in the areas of the interest (figure 4).

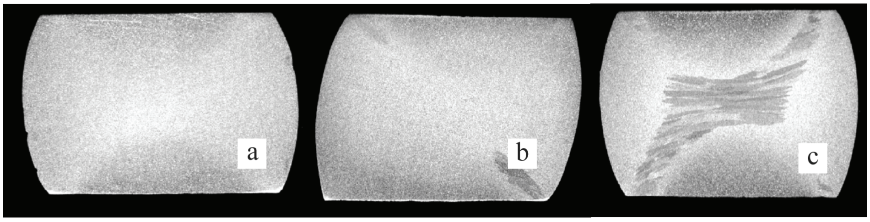


Fig. 2. Macrostructure of the samples from AB alloy after heating to 520°C during 1 hour and then quenched in water. Ram velocity is 1,5 mm/s. Deformation temperature: a – 430°C, b – 415°C, c – 407°C.

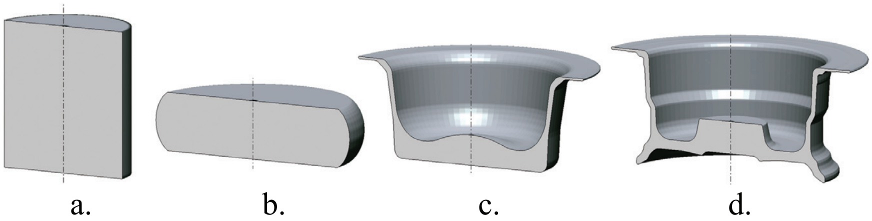


Fig. 3. Technological operations of forging of car wheel's disc in split dies: a – initial workpiece; b – upset workpiece; c — mould blow; d — finish forging.

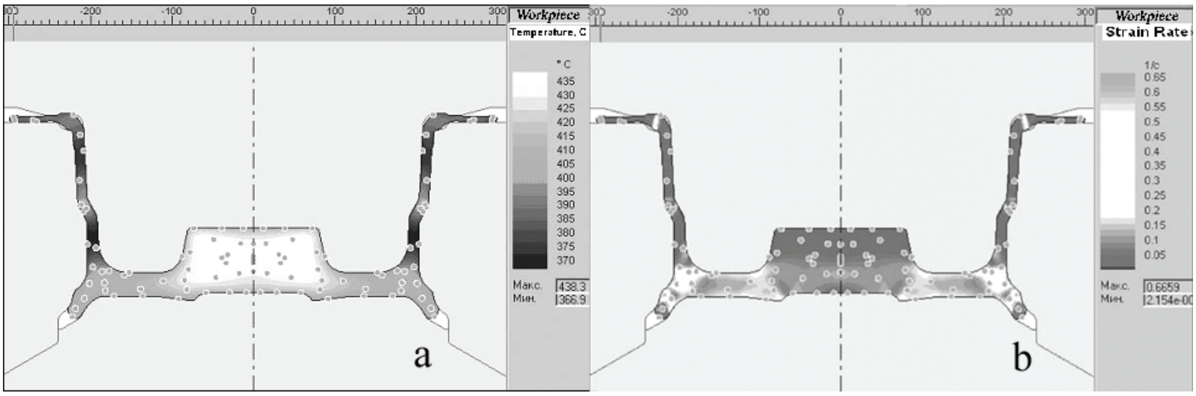


Fig. 4. Distribution of temperature (a) and strain rate (b) in the wheel forging cross-section at the final stage of finish forging.

3. INVESTIGATION RESULTS AND DISCUSSION

The investigations were carried out for the most dangerous areas of the forged parts: web, crown, upper and lower flanges (figure 5). Superposition of the simulation results to the diagram of structural conditions of AB alloy (figure 1) after deformation and heating shows that all the selected areas are located in the most dangerous zone III. However, taking into account the critical value specified above (lg Z = 14) we can say that only the upper and the lower flanges are located entirely in the zone of supercritical values of Zener-Holomon's parameter, as well as the parts of the web (points 42, 28, 38) and the crown (point 48). The reason of this is that at the final forging stage the metal is deformed in the direction of the lower flange. The web and the crown are deformed intensively as well. Besides of this the upper flange is formed finally.

The web area is marked by points 28 and 38 (figure 5) and moves intensively towards the cavity of the lower flange while the dies are closing. First of all it is seen in the principal difference of the strain rate conditions (figure 6a). Beginning from the 7th second of the forging process the strain-rate increases rapidly up to 0.7 - 1.0 s^{-1}, which causes the supercritical lg Z values (14.2 - 14.6).

The beginning of metal flow towards the lower flange concurs with the beginning of intensive reduction of the web. However, together with the slender cooling-down (no less than 440°C) the metal deformation is characterized here by the high strain rate especially at the finish forging stage. During the process the areas around the points 36, 47 and 46 are moved into the cavity of the lower flange, which has the form of narrowing channel with bend. The point 36 manages to go through the whole way. The maximums and minimums at the dependence of strain rate agree with quantity and sequence of channel bends (figure 6b).

In spite of the discovered dependence of lg Z on the temperature and the strain-rate parameters of deformation it's impossible to give a final conclusion about the priority of the influence of the temperature or the strain-rate on lg Z and on the accumulated energy level correspondingly. The problem of supercritical values of lg Z can be solved by control of the temperature and the strain-rate. It is impossible to exclude cooling down without additional production costs. Theoretically, this problem can be solved by using isothermal forging, but this is impractical for mass production of aluminum parts.

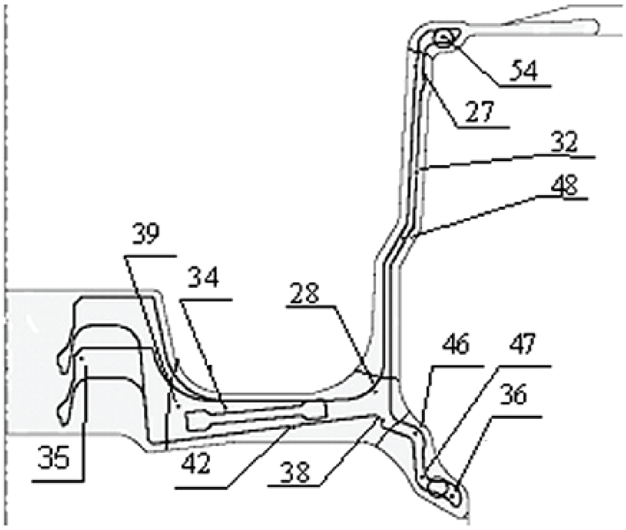


Fig. 5. *Tracked points scheme in forging elements within the limits of profile of finished part. The points numbers are shown.*

The velocity of movement of hydraulic press ram is a result of the compromise between required forging force and maximum available force of the press. On the other hand, the flow stress of the deformed material depends on strain rate and due to decreasing of the press ram velocity it will be smaller. This allows to control the workpiece strain-rate by restriction of the forging force by means of hydraulic press valve. This method is known as creep forging and is used for isothermal forging of the parts from high strength metals and alloys with the purpose of improving the dies operative conditions. Analysis of the results of computer simulation of such technology shows that such strain-rate conditions can be more preferable in case of the guaranteed die cavity filling. As a result of this the maximum level of lg Z acting in the web and the lower flange (see Fig. 7) at the end of the forging process does not exceed the critical value of 14. The most important fact is finishing of the forging process by lg $Z < 14$.

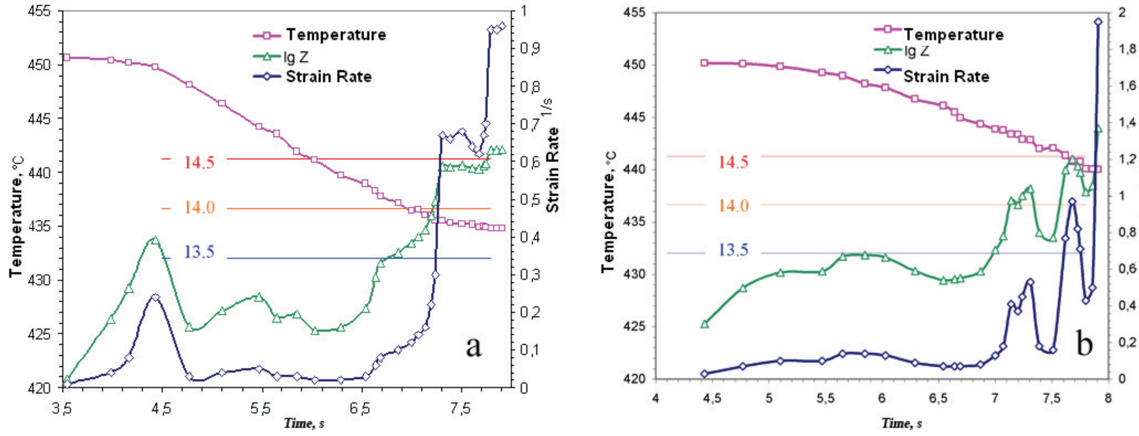


Fig. 6. *Time dependences of temperature, strain rate and lg Z for the web area in the point 38 (a) and the lower flange in the point 36 (b). Numbers over the horizontal lines are the levels of lg Z.*

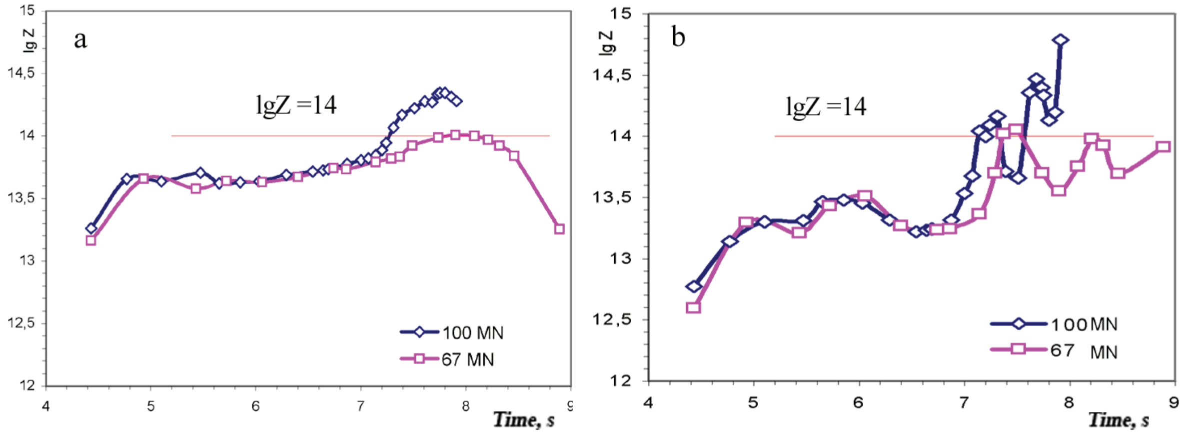


Fig. 7. *Change of lg Z value during the finish forging on press operating with 100 MN (◊) and 67 MN (□) maximum force. The point in the web is 38 (a) and the point in the lower flange is 36 (b).*

4. CONCLUSIONS

1) The simulation results obtained by QForm allow to control the temperature and strain-rate conditions during the forging process and to reach the specified level of mechanical properties.
2) The method of prediction and control of the forged part micro structure is described and illustrated by the example of technology of forging on hydraulic press of car wheel's disc from AB aluminum alloy in a split die.

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WYKORZYSTANIE PROGRAMU QFORM DO SYMULACJI ZMIAN MIKROSTRUKTURY PODCZAS PROCESU KUCIA

Streszczenie

Optymalizacja procesów kucia oraz obróbki cieplnej w celu osiągnięcia zadanych właściwości mechanicznych oraz odpowiedniej struktury materiałowej możliwa jest dzięki rozbudowie oprogramowania przeznaczonego do symulacji tych dwóch procesów. W niniejszym artykule przedstawiono metodę modelowania struktury oraz właściwości materiałowych przy użyciu parametru Zenera-Holomona dla procesu kucia na gorąco felg aluminiowych. Badania przeprowadzono dla najbardziej krytycznych obszarów kutej części takich jak żebra usztywniające czy też dolnego i górnego kołnierza. Metody modelowania struktury zastosowane zostały dla kucia na gorąco dla felg z aluminium AB na prasie hydraulicznej z dzieloną matrycą.

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