INFLUENCE OF CAVITY SHAPE AND ENTRY HOLE ON MINITHIXOFORMING

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Abstract

Metal forming in a thixotropic state is an alternative forming method which enables production of irregular and complex shaped semiproducts. The entire process is carried out in one forming step in a closed hollow die and the necessary forming forces are, because of the thixotropic state, minimal when compared with conventional forming processes. Another considerable advantage is the ability to work otherwise hard-to-form or difficult-to-machine materials. Working with metals in a thixotropic state is however technologically demanding, especially for metals with high melting temperatures. For minithixoforming, i.e. the application of thixoforming to small parts, ANSYS software was used to create a numerical model of variants of the form cavity and entry hole. The simulation was used to design and build a form with a variable cavity shape and practical minithixoforming experiments were performed on X210Cr12 steel in the cavity. The initial phase of the experiment tested the basic forming parameters, in particular the force and temperature of forming. After successfully filling the form cavity, the form cavity and entry hole were varied to test the variability of this technology. Also tested was the fluidity as the diameter of the entry hole was reduced. The influence of reducing the cross section was not evaluated only from a technological standpoint, but also the development of the microstructure with reduction of the dimensions of the entry hole and the thickness of the walls of the semiproduct. The resulting microstructure was assessed using optical, laser confocal and electron microscopy.

Key words: Semi-solid state, minithixoforming, rapid cooling

1. INTRODUCTION

One forming method which is very seldom used commercially is working metal in a semi-solid state. The technology is in widespread commercial use for alloys with low melting temperatures [1]. Despite its great potential, it has until now not been used for metals with high melting temperatures, namely steels. A special group of approaches for manufacturing small components in the semi-solid state is called 'minithixoforming' [2]. The whole process is however technologically very demanding and requires the development of new approaches for controlling the temperature field within the small volume (up to 1 cm³) of the material. During heating, minimum temperature deviations must occur to achieve even temperature distribution throughout the semiproduct. A further advantage of thixoforming is the very rapid solidification from the semi-liquid state after deformation. This approach can achieve unconventional types of structure even for materials commonly used in industry. They acquire an interesting combination of not only mechanical but also physical properties. They are multiphase structures which arise as a result of uneven rate of solidification.

2. DESIGN OF EXPERIMENTAL APPARATUS

Apparatus working on the principle of lateral extrusion was designed for the minithixoforming process (Fig.1). The form consists of a two part titanium shell with an external diameter of 80mm and an internal lining. It is separated into four parts to enable easier removal of the product. The lining was made of titanium, but in the future different materials will be used with a range of thermal conductivities enabling the influence of the rate of cooling on the development of the microstructure to be monitored. The height of the assembled form is
40mm. The internal shape of the cavity, and thus the resulting product, is defined by a forming plate. By changing this, it is possible to rapidly achieve a change in the shape of the resulting product. To heat the semiproduct, copper electrodes with internal, precisely defined tapers are used which ensure centring of the semiproduct and contact transfer of current. The temperature of the semiproduct is continually monitored by thermocouple which is attached by a corundum tube drilled into the form.

Fig. 1 Minithixoforming with lateral extrusion

2.1. Selection of materials for thixoforming

X210Cr12 machine steel was selected for the experiment (Tab. 2). It has a wide temperature interval between solidus and liquidus which means it is suitable for working in the semi-solid state [3]. This material is also characterized by the fact that it is hard-to-form and machine using conventional methods because its high chrome content makes it very hard and quite fragile. The initial structure is formed of a ferrite matrix with globular cementite and primary chrome carbide (Fig.2).
Fig. 2 Initial structure of X210Cr12 steel

Table 2 Chemical composition of X210Cr12 steel measured by emission spectroscopy

<table>
<thead>
<tr>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Si</th>
<th>Ni</th>
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<td>0.08</td>
<td>0.014</td>
<td>0.001</td>
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</table>

3. NUMERICAL SIMULATION OF MINITHIXOFORMING

ANSYS 10.0/ FLOTRAN software was used for numerical simulation. Because of the high complexity of the calculation, the initial task was simplified to a 2D model on which was investigated the basic property of the ability of the material to fill the form cavity in relation to the shape of the form cavity.
Five variants of the cavity were designed, all with the same length but with differently shaped entry holes and groove geometries (Fig.3). The temperature dependence of material properties was used as the input data for the steel. These values were calculated for a temperature range 0 - 1500°C. The simulation was used to investigate the speed of filling of the cavity in relation to the geometry and also the speed of solidification and the ability to fill the cavity. On the basis of the results from the numerical simulation it was seen that, in terms of fluency and speed of filling, the most suitable cavity shape is variant E. Filling of the cavity in this case is completely even. Studying the temperature field during thixoforming confirmed that at sufficient speed it is possible to completely fill the cavities of all the variants, a condition is however the high dynamism of the whole process. Only 0.3s after the beginning of the forming process, the temperature has dropped to the solidus boundary. No less advantageous was variant A where the width of the entry hole and the entire channel is 3mm, with which is related the speed of heat transfer, and variant C where at low filling speeds, solidification may occur in the entry hole.
Fig. 4 Distribution of temperature fields

4. MINITHIXOFORMING

The rapid solidification during minithixoforming allows unconventional structures to be obtained even with completely conventional materials. From a technological viewpoint it is important for the material to have the highest possible temperature throughout the whole deformation process in order for the cavity to be adequately filled. However this can lead to the danger of overheating the form resulting in the slower cooling of the material. It is therefore essential to accelerate as much as possible the whole thixoforming process to avoid this undesirable result. For the first experiment, on the basis of numerical simulation, a simple straight cavity was built with the following dimensions: width 5mm, length 15mm and thickness 3mm. This cavity served to find the forming parameters and to confirm their agreement with the values calculated from the numerical model. Some of the key parameters of the thixoforming process are forming temperature, deformation speed and forming force. If all these parameters are not maintained within precise limits, the cavity will either be imperfectly filled or the material will not flow at all. After optimizing parameters, all these cavities were filled, including sharp edges and corners (Figs. 5a and 5b). The optimal forming temperature
for the material was set at 1265°C, speed of deformation 1m/s and maximum force was limited to 7kN. The next step was to reduce the entry hole and extend it. The thickness of the cavity was reduced to 1.5mm and extended to 20mm whilst maintaining a width of 5mm and retaining the optimum forming parameters. Even at this thickness the cavity was completely filled.

After experimenting with a straight cavity, a number of shaped demonstrators were designed on which the ability to fill cavities with tapered inlet holes was tested. Because of the modular assembly of the die it was possible to change not only the shape of the cavity but also the entry hole by merely changing the form insert. It was shown that, with sufficient volume of melted material, metal in a thixotropic state can fill a conically tapering cavity with an opening of 2mm which narrows to 1.8mm along a length of 15mm (Fig.6).

5. METALLOGRAPHIC ANALYSIS OF THE SEMIPRODUCTS

Metallographic analysis showed that after thixoforming the structure of X210Cr12 steel is formed of polyhedral grains of austenite surrounded by a fine carbide network (Fig. 7). Repeated XRD phase analysis revealed a 96-ti % share of austenite in the structure. The origin of such a high proportion of austenite was due, apart from the chemical composition, to the high heating temperature and the rapid solidification and cooling and the development of the structure under high pressure.

The hardness of the structure after thixoforming was 320 HV30. In the cross section between semi-product body and extruded product the dendritical zone in the contact area with the die was observed (Fig. 8). The macro view of this area showed that the material flow occurred in the central part of the die cavity.
6. **CONCLUSION**

This work showed that by forming X210Cr12 steel in a semi-solid state, very small component with various shapes can be created. Thixoforming was carried out in the die cavity and the shape of demonstrators was varied. The results show that the ability of the material to fill the entire volume of the die cavity is excellent, provided there is a sufficient amount of molten metal in the required dynamics of the process, as cooling of the melt begins after a fraction of a second. The smallest entry hole was 2mm x 2mm. Despite the rapid transfer of heat, the cavity was excellently filled. After thixoforming the microstructure was composed of polyhedral austenitic grains surrounded by a fine carbide network.

**ACKNOWLEDGEMENT**

The paper includes results obtained within the project 1M06032 Research Centre of Forming Technology and Slovak and Czech Project SK-CZ-0180-09.

**REFERENCES**

