journal of materials processing technology 199 (2008) 304–313

journal homepage: www.elsevier.com/locate/jmatprotec

Evaluation of microstructure change and hot workability of high nickel high strength steel using wedge test

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ARTICLE INFO

Article history:
Received 23 August 2006
Received in revised form
21 June 2007
Accepted 3 August 2007

Keywords:
Forging
Wedge test
Hot workability
High nickel high strength steel

ABSTRACT

In the present paper, a new method is introduced for establishing the suitable hot working condition in order to attain desired microstructure without fracture by combination of simulation results and outcomes of limited forged wedge specimens. Two high nickel high strength steel grades were chosen for demonstrating the ability of new proposed technique even for high alloy materials. Numerical simulations and experimental hot forging of wedge specimens had been carried out at 950, 1100 and 1200 °C. At these temperatures, it became possible to relate the microstructural changes to deformation behavior by using combination of simulations and experimental results and as an example, critical strains for beginning of dynamic recrystallization had been defined. The plastic strains before appearance of surface fractures were also determined at temperatures of 1100 and 1200 °C. Comparison of strain at fracture position for hot deformed wedge specimens and tensile specimens at 1100 °C shows similarity of tensile strains at fracture.

1. Introduction

The aims of hot forming processes such as rolling or forging are mass production of final goods or semi-final products with desired shape accuracy and mechanical properties. The nature of hot forming processes is thermo-mechanical, while many factors influence the physical properties of the product. These factors vary from process parameters such as temperature, tool's velocity and friction to material parameters like chemical composition, microstructure and so on. The interactions of mentioned parameters determine the final properties of the product and it is desired to express the properties as a function of process and material parameters. For expressing such a relation, preliminary data is required first. The examples of the preliminary data are; the effect of strain and strain rate on the microstructure changes during hot deformation, effect of loading condition on the deformation behavior, effect of temperature and frictional condition on the deformation behavior and hot workability range (Dieter, 1984; Maki et al., 1981, 1982; Roberts, 1985). For evaluating the above-mentioned parameters, according to loading condition of the real break down process, various simplified tests such as hot tension, hot compression, hot torsion, or more complicated tests such as wedge compression, side pressed bar and so on can be used independently (Dieter, 1984). Preliminary data collection for various production lots or new materials based on such simplified test, become very tedious task, since many tests at different tem-

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0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2007.08.015

peratures should be carried out in order to gather the require data.

Therefore, if it is possible to limit the number of tests or required specimens beside of using testing techniques with more similarity to the reality, the data can be collected more economically and in a shorter time. Wedge compression test seems to be a good candidate for satisfying some of the mentioned criteria, since it shows good similarities to the real situation in hot forming processes. Limiting the number of required specimen or tests could be achieved by combination of numerical and experimental methods.

Various materials with distinct properties and response to loading condition at high temperatures are subjected to hot forming processes. Today's trend in weight reduction without losing of strength has caused the selection of high nickel high strength steel for present research. In 1960s, it had been revealed that adding Titanium, Cobalt or Tungsten to low carbon steel containing high percent of Nickel could lead to high strength steel with distinguished properties (Floreen, 1978; Schmidt and Rohrbach, 1978). Even this kind of steel had interesting properties in as cast condition, but for many applications, it must have been deformed at high temperatures in order to acquire necessary optimum properties such as desired shape, improving mechanical properties and possibility of further deformation at room temperature.

In the following sections, research procedures and attained results related to the idea of combining numerical simulation and experimental compression test on the wedge shape specimen made of high Ni high strength steel grades will be presented.

2. Problem definitions and research procedures

Wedge compression test is one of the applied methods for microstructural evaluation due to hot deformation (Dieter, 1984). Wedge samples consist of a constant height portion, which acts as the reference point for microstructural evaluation and variable height with fixed width. At constant descending velocity of upper die, since wedge's height varies along its length and friction exists at the interface between dies and specimen, strain and strain rate varies during deformation along the length and at any section. In addition, chilling effect of dies and heat transfer to the surroundings should be added to the complexity of process during hot deformation. In spite of existence of such complications, there is a good similarity between loading situation and obtained microstructural changes in forged wedge specimen and real microstructural variation during the hot deformation of ingot and billets (Dieter, 1984).

For evaluating the hot workability range, different simple methods (such as hot tension, hot compression or hot torsion) can be carried out and results of such tests give valuable insight about variation of different encountered mechanisms with temperature during hot deformation (Dieter, 1984). However, the states of stresses in real hot deformation situations (such as forging and rolling) are much more complicated than the state of stress in simple tests. Therefore, they cannot be used efficiently for evaluating hot workability. Hot compression test that shows similarities to some extend to the real cases is an exception, although this test requires several specimens for examination of different conditions. Nevertheless, the wedge compression technique can be used to define the deformation limit due to the appearance of surface cracks under biaxial tension by increasing of deformation.

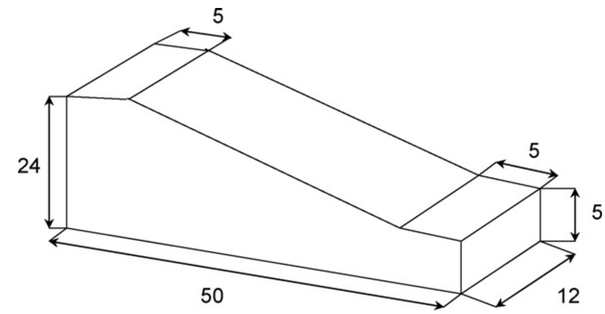

Fig. 1 – The shape and dimension of wedge used in simulation and experimental work (units in mm).

Therefore, wedge compression test results can lead to establish some approximation between the amount of deformation and microstructural changes and hot workability as a function of temperature, simultaneously. However, it is rather difficult or impossible to deduce the strain and strain rate at different positions and their effects on the microstructural evaluation and appearance of surface cracks in experimental specimen. Nevertheless, if experimental and simulation techniques are combined, it becomes possible to deduce the required information. Based on the mentioned idea, it has been tried to use combination of simulation and experimental results of wedge compression test for accessing the desired data. Used wedge test specimen dimension for experimental investigations and simulations are shown in Fig. 1, which have the capability of about 80% height reduction. For simulations of wedge compression test, suitable commercial finite element software with the ability of calculating large deformation has been selected. Then by using simplified boundary conditions similar to the expected experimental requirements, wedge compression tests have been simulated. In the next step, the experimental works have been carried out and from the combination of results, an attempt has been made to access the desired information. In the followings, details of simulation and experimental procedures will be explained.

2.1. *Simulation procedure*

Because of three-dimensional state of strain in hot forging of wedge samples, the exact value of strain could not be easily estimated and therefore simulation had been used. For simulations of wedge compression test, because of historic dependence of deformation behavior of the alloy, update Lagrangian method had been used with the aid of static linear solution method.

Wedge specimen model had been discretized using brick elements with 20 nodes for compression test simulations. Commercial software and selected elements had capability of simulations for non-linear large deformation. During