Journal of Metallurgical and Materials Engineering, Vol.32, No.2, 2021.

Predication of Hot Flow Behavior of Micro-Alloy Steel Using Modified Johnson-Cook Model

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1 Introduction

Micro alloy steel is one of the medium carbon steels, which are commonly used as seamless tubes in the gas and oil industry. Generally, the seamless steel tubes are manufactured by hot forming processes such as hot extrusion and hot rolling. During the production process, microstructural changes and phases transformations occur which affect the mechanical properties and corrosion resistance of steel tubes. Therefore, understanding of hot working behavior of these steels could be helpful to fabricate components with desired mechanical and metallurgical properties. The thermomechanical processes of materials exhibit complicated behaviors at deformation variables that produce high-quality parts with desire mechanical and microstructural characteristics.

Most of the researchers have extensively used mathematical and empirical models to predict the hot deformation behavior of materials under complex loading. Therefore, different models are proposed to exhibit high accuracy of hot flow behaviors. These models are used as computer codes to simulate hot forming processes under different strain rates and temperatures. Constitutive models are generally divided into different categories including empirical, phenomenological, physical, and numerical models to predict different behavior of metals and alloys. A large number of researchers, based on the experimental results, have developed the Johnson-Cook model to predict the hot deformation behavior of materials. The effects of deformation temperature, strain, and strain rate were considered in the different terms of the model. However, due to the significant effects of dynamic deformation mechanisms like dynamic recovery and dynamic recrystallization on the hot flow behavior, the modifications are considered in order to increase the prediction accuracy of the Johnson-Cook model. The modified Johnson-Cook models can indicate accurately the hardening and softening behavior of materials at flow stress curves under different complex conditions.

The main aim of this work is to characterize the high-temperature deformation behavior of micro alloy steel through isothermal compression tests under different deformation temperatures and strain rates. Hot flow stress and microstructural behavior of the deformed micro alloy are investigated. A modified Johnson-Cook model for the description of the hot deformation behavior of this steel is developed, as well.

2- Experimental

The cylindrical specimens with standard dimensions Ø10 × 15 mm were machined and hot compressive test was carried out to exhibit hot flow behavior under temperatures ranging from 1173 K to 1373 K and strain rates from 0.001 s^{-1} to 1 s^{-1}, with a true strain of 0.6. After the compression test was completed, each specimen was immediately quenched to maintain the microstructure changes under different conditions. Finally, deformed specimens are sectioned, finished, polished, and etched to illustrate microstructure changes.

3- Results and Discussion

The microstructural analysis of the deformed specimens of the micro alloy steel is illustrated in Fig. 1. It can be seen that the equiaxed compressed grains are formed under different deformation conditions describing the dynamic recrystallization mechanism that occurred during the hot compression tests, compared with initial morphology. Therefore, dynamic recrystallization plays an important role in the hot flow behavior of micro alloy steel.

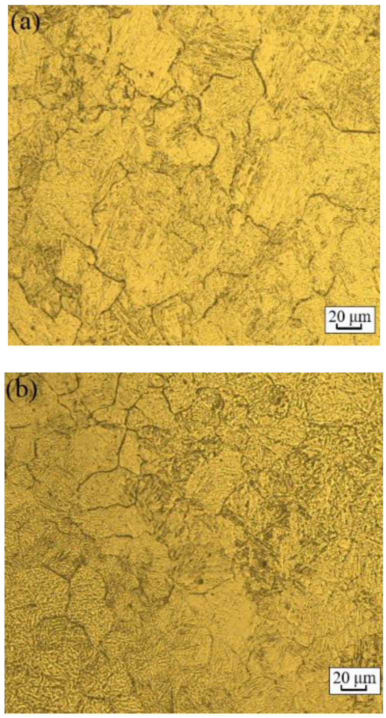

Fig. 1. Optical micrograph of deformed specimens.

The modified Johnson-Cook model was purposed to indicate the predominant hardening and softening behaviors and the effects of deformation parameters on the flow stresses of the micro-alloy steel, considering the effects of strain, strain rate, and deformation temperature. Finally, the developed Johnson-Cook model is obtained as:

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$$\sigma = (77.642 + 419.11\varepsilon - 504.2\varepsilon^2)(1 + 0.085\ln\dot{\varepsilon}^*)\exp[-(0.0047 + 0.000031\ln\dot{\varepsilon}^*)T^*]$$

The comparison between the measured and predicted results by the modified Johnson-Cook model at various conditions for micro alloy steel is shown in Fig. 2.

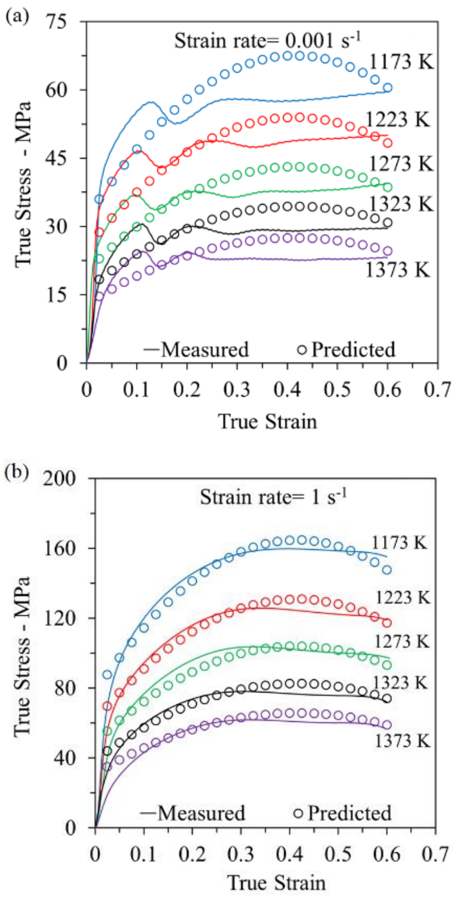

Fig. 2. comparison between the measured and predicted results by the modified Johnson-Cook model

This figure showed that the hot compressive behaviors of studied steel significantly depend on the dynamic recrystallization as a key softening mechanism. This mechanism results in a complex flow behavior in the form of multi-peak and single peak curves under different deformation conditions. it can be seen that the modified Johnson-Cook model could correctly predict the flow behavior of steel. So, there is a suitable correlation between the experimental and predicted data. At the strain rate of 1 s^{-1}, the modified model has completely accurate predictions under different deformation temperatures. However, at other strain rates due to severe changes of flow stresses as single peak and multi peaks curves, the modified model cannot comprehensively indicate the softening behaviors of micro alloy steel.

4- Conclusion

The investigating of the hot deformation behavior of the micro alloy steel under hot working conditions indicated that the dynamic recrystallization phenomenon was the main deformation mechanism at the entire forming conditions that depicts its effects on the stress-strain curves as multi and single peak flows. In addition, the developed Johnson-Cook model was capable of predicting the flow behavior of studied steel, especially at the highest strain rate.