Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 10 (2011) 752–757

Engineering Procedia

ICM11

Damage evolution during cross wedge rolling of steel DIN 38MnSiVS5

M. L. N. Silva[a]*, G. H. Pires[a] and S.T. Button[a]

[a]*School of Mechanical Engineering – University of Campinas, Campinas 13083-970, Brazil*

Abstract

The study of variables which influence the formation of central cavities is a constant theme in recent works about Cross Wedge Rolling (CWR). Damage modelling typically used for analysis of cold forming processes, can also be useful for the study of critical conditions in hot forming processes. Varying geometric and process parameters, damage distribution provided important information about the conditions which favor the formation of defects in parts during manufacturing. Using the Hansel-Spittel's rheological law equation, it was studied the behavior of the microalloyed steel DIN 38MnSiVS5 simulated with the finite element method (FE). Tests were carried out in an equipment available at the Metal Forming Laboratory (MFL) to validate the adopted numerical models. In those tests and simulations the stretching angle was kept constant, and three variables were evaluated: forming angle, relative reduction and speed. For this microalloyed steel the high sulfur content associated with a high working temperature determined the formation of large central cavities in the rolled parts which could be also predicted in the simulations.

Selection and peer-review under responsibility of ICM11

Keywords: Cross wedge rolling; Finite element method; Hot forming; Internal defects; Microalloyed steel.

1. Introduction

In Cross Wedge Rolling (CWR), a forged part or a cylindrical billet is formed by wedge-shaped dies which are fixed in rolling mills or plates. In comparison with conventional manufacturing processes, i.e., machining, forging or casting, the cross wedge rolling process is characterized by many advantages, particularly high efficiency, better material utilization, better mechanical properties, reduced energy consumption, facilitated automation and environment harmlessness [1]. Until this moment, the plastic forming mechanisms of CWR are not totally clear due the complexity of the metal forming and thus

---

* Silva, M. L. N. Tel.: +55-19-35213398
E-mail address: marioluiznunes@gmail.com

Selection and peer-review under responsibility of ICM11 doi:10.1016/j.proeng.2011.04.125

experimental research is still dominant. The lack of precise theories leads to experiments with many repetitions in which products defects are hardly controlled, as well as porosity, voids and cracks initiation, and therefore these defects limit the use of the process in large scale [2].

The first objective of this work was to study the influence of the process variables in the generation of the central cavities in rolled parts made with the microalloyed steel 38MnSiVS5 based on practical tests and numerical simulations with the software Forge 2008.

The second objective was to establish the influence of the inclusions present in the microalloyed steel 38MnSiVS5 on the crack generation that origin the internal defects.

The choice of that steel, whose chemical composition is shown in Table 1, was due to the fact that microalloyed steels are increasingly used in the automotive industry, because they represent a great saving of time and energy since they do not require subsequent heat treatment reaching good mechanical properties when cooled from hot working temperatures.

Table 1. Chemical analysis of microalloyed steel 38MnSiVS5 (% in weight)

C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al	N
0.37	1.41	0.60	0.014	0.055	0.11	0.10	0.02	0.09	0.04	0.011	0.0157

2. The CWR Process

Many authors have described the plastic deformation along the various zones of the tools [3, 4]. At this point, it is important to know the key parameters of the process related to tool geometry: the forming angle α on the wedge side, the stretching angle β of the wedge, and the relative reduction δ, or the ratio between the initial diameter of the billet and the smaller diameter of the rolled product (Fig. 1)

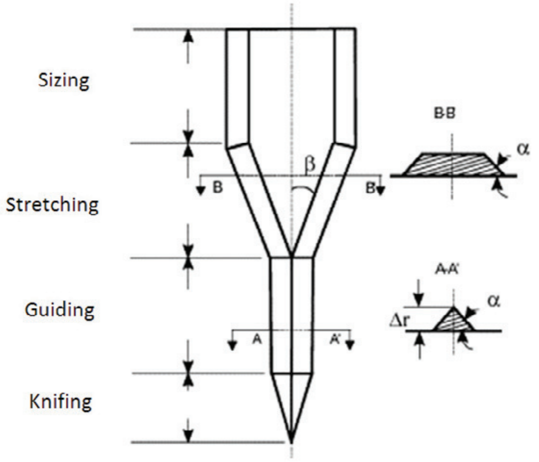

Fig. 1. CWR Tools zones

These parameters determine the plastic forming level experimented by the workpiece and they have a relevant role in the probability of internal defects occurrence. The forming angle α, for example, controls the contact area between tools and rolled part. Smaller angles mean less sharp tools and a larger contact area with the part.

The stretching angle β determines the total axial deformation, so larger stretching angles mean larger plastic deformation and elongation.

The relative reduction δ is a measure of the radial reduction of the rolled part. The larger the relative reduction, the larger the radial compression suffered by the part [5].

Besides these geometric variables, the rolling speed (v) was also considered in this research [6].

3. Numerical Simulation

In this paper numerical simulations were carried out with the software Forge 2008 to analyse CWR of the microalloyed steel 38MnSiVS5. Its rheological behavior was obtained through hot tensile and torsion tests. The material parameters of the Hansel-Spittel model were determined and implemented into the FE program library.

Workpieces were discretized with a constant mesh size equal to 2mm, with a total of 14,000 elements on average. This mesh size represents a medium accuracy to the process and a reasonable time processing. The workpiece was pre-heated at 1100^{o}C and the tools were considered at room temperature, 25^{o}C; data from the Forge 2008 database were used for heat transfer and friction parameters. Billet diameter was 24 mm and its length was 80 mm. The velocity of the tools was 200 mm/s, which is the same of the experimental tests.

Two different forming angles were analyzed: 10^{o} and 25^{o}. Regarding to generation of the central cavities, the first angle is more aggressive to the process, and the tools with forming angle of 25^{o} corresponds to the dies used in the experimental tests.

4. Damage

Damage is usually associated with the fracture in a component. Particularly, the damage model developed by Cockcroft-Latham, which is one of the damage models available in the software Forge 2008 [7], has been shown to be a good indicator of ductile fracture under tensile stress. In this study, a normalized Cockcroft-Latham method, given by Equation 1, was chosen, where σ_1 is the maximum principal stress and the main responsible for the fracture initiation, $\bar{\varepsilon}_f$ is the equivalent fracture strain, $\bar{\sigma}$ the equivalent stress and D is the amount of damage.

$$D = \int_0^{\bar{\varepsilon}_f} \frac{\sigma_1}{\bar{\sigma}} d\bar{\varepsilon} \qquad (1)$$

An important feature of the software Forge 2008 is the so-called “trigger” used with the killing element technique. It allows a particular element to be deleted when the value of the damage variable reaches the value determined by the trigger. This value of damage is called Damage critical value (D_c) given by Equation 2.

$$D_c = \frac{\sigma(\varepsilon_f) - \sigma_D(\varepsilon_f)}{\sigma(\varepsilon_f)} \qquad (2)$$

where σ is the tension value of the integral workpiece, σ_d the tension value of the damaged workpiece, both of them at the rupture [8].

The parameters needed to determine the value of the trigger were obtained coupling the results of hot tensile tests with corresponding results obtained in the numerical simulations. Analyzing the CWR simulations, the strain rate of the process was determined and helped to establish the speed in the hot tensile tests and consequently the strain rate since it was desirable that the hot tensile tests presented the same strain rate of the CWR process. These values varied from 2.7 to 3.5.

Simulations of hot tensile tests were done with the same variables of the experimental ones, including the same workpiece geometry. The results of tensile tests are shown in Fig. 2. Two values of trigger were adopted: 0.4 (near of reduction of 0.36) and 0.6 (near of reduction of 0.41) because the curve of experimental tests did not evidence the exact point of rupture of the workpiece, due to the strong necking.

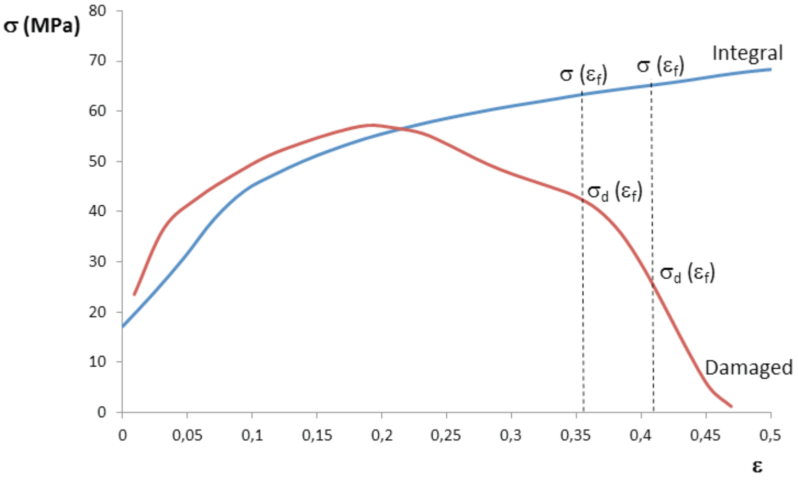

Fig. 2. Hot tensile tests curves: red – experimental test, blue – simulation results

5. Experimental tests

In this study the process and geometric variables showed on Table 2 were considered.

Table 2. Process and geometric variables

α (°)	β (°)	δ	T (°C)	v (mm/s)
20	7	1.61	1100	100
20	7	1.61	1100	150
20	7	1.61	1100	200
20	7	1.57	1100	100
20	7	1.57	1100	150
20	7	1.57	1100	200
25	7	1.51	1100	100
25	7	1.51	1100	150
25	7	1.51	1100	200

After the tests under the conditions showed in Table 2, the rolled parts were sectioned transversally in relation to the main axis in the central region to analyse the presence of defects.

6. Results

6.1. Numerical simulations

To analyze the formation of central cavities, it was decided that the damage variable would be the better way to understand the influence of the material and process and geometric variables. The killing element technique proved to be useful to point the beginning of the internal defects.

Figure 3 ($\alpha = 10^{o}$ and trigger = 0.4 and 0,6) and Fig. 4 ($\alpha = 25^{o}$ and trigger = 0.4 and 0.6) present the workpiece at the beginning of stretching zone. Both figures show the notable influence of forming angle. The stress concentration in the center of the part leads to a high level of damage at the beginning of the process with $\alpha = 10^{o}$. Differently, when working with $\alpha = 25^{o}$, larger stress concentration can be found near the surface and it does not cause the formation of central cavities. No significant difference was noticed between the two triggers.

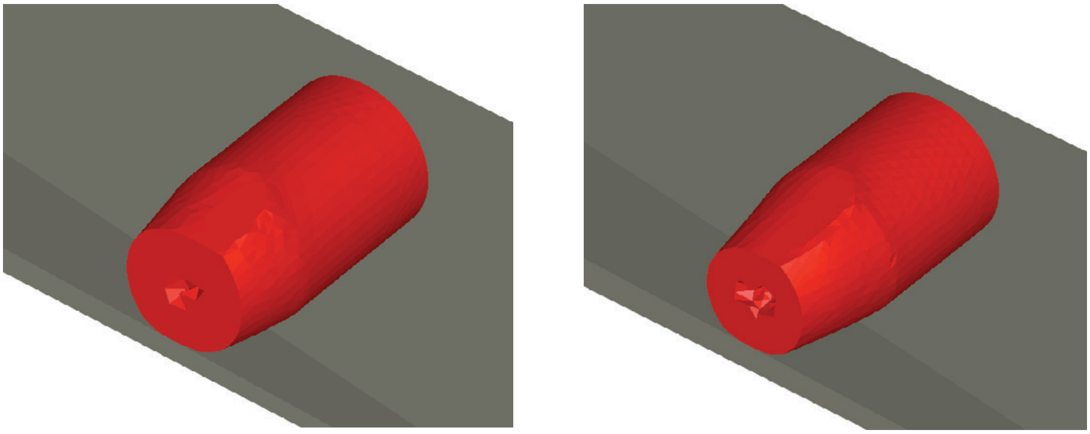

Fig. 3. (a) $\alpha = 10^{o}$ and trigger = 0.4 (b) $\alpha = 10^{o}$ and trigger = 0.6

6.2. Experimental tests

Many tests with workpieces made with carbon and microalloyed steels have been performed at the MFL. Previous studies emphasized the influence of the forming angle and the relative reduction on the formation of internal defects when working with a carbon steel [6]. Tests with smaller relative reductions and larger forming angles produced rolled parts with no defects [8].

At least two workpieces were rolled in each condition described in Tab. 2. Although it is believed that the microalloyed steel 38MnSiVS5 was a nobler material, all rolled parts presented large central cavities. Metallographic analysis revealed the high content of manganese sulfide inclusions present in this material. For this steel and with this inclusions content, the inclusion influence on the defects generation prevailed over the process and geometric variables influence.

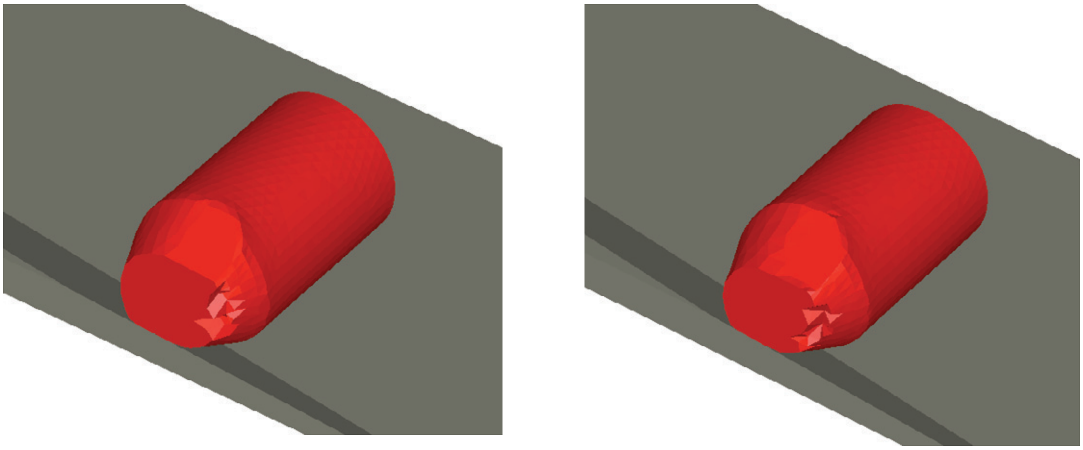

Fig. 4. (a) $\alpha = 25^{\circ}$ and trigger = 0.4 (b) $\alpha = 25^{\circ}$ and trigger = 0.6

7. Conclusion

The rheological behavior of the microalloyed steel DIN 38MnSiVS5 was identified and implemented into the FE program library. Experimental and simulation tensile tests were performed in order to compare their results and to define the trigger to be used with the killing element technique.

Numerical simulation based on the finite element method proved to be a valuable but not definitive tool to predict the formation of central cavities in CWR process. As an auxiliary tool, it can be useful to determine process limiting conditions.

At conditions where workpieces made with carbon steel did not present internal defects, others made with microalloyed steel 38MnSiVS5 presented large central cavities. High manganese sulfide inclusion content and high temperatures of hot working are the most important factors to internal crack formation.

Acknowledgments

Authors wish to thank the financial support given by FAPESP.

References

[1] Pater, Z. Finite element analysis of cross wedge rolling. *J of Mat Proc Techn* 2006;**173**:2, p. 201-208.

[2] Wang, M., Li, X. & Du, F. Analysis of Metal Forming in Two-Roll Cross Wedge Rolling Process Using Finite Element Method. *Int J of Iron and Steel Res* 2009;**16**:1, p. 38-43.

[3] Silva, M. L. N., Regone, W. & Button, S. T. Microstructure and mechanical properties of microalloyed steel forgings manufactured from cross-wedge-rolled preforms. *Scripta Materialia* 2006;**54**:2, p. 213-217.

[4] Dong, Y., Tagavi, K. & Lovell, M. Analysis of interfacial slip in cross-wedge rolling: a numerical and phenomenological investigation. *J of Mat Proc Techn* 2000;**97**, p. 44-53.

[5] Qiang L., Michael R. L. & William S. Experimental Investigation of Internal Defects in the Cross Wedge Rolling Process. *J of Mat Proc Techn* 2002;**125-126**, p. 248-257.

[6] Silva, M. L. N. and Button, S. T. Numerical Simulation of Cross Wedge Rolling: Influence of Die Geometry, Process Conditions and Inclusion Content of Two Steels on the Formation of Internal Defects. *Proc. 4th Int Conf on Advanced Comp Eng and Experimenting* 2010, Paris.

[7] *Forge Online Help*, version 3.1. 2008. Edited by Transvalor S.A.

[8] Fanini, S., Ghiotti, A. and Bruschi, S. Prediction of the fracture due to Mannesmann effect in tube Piercing. Materials Processing and Design; Modeling, Simulation and Applications. *Proc, of the 9th Int Conf on Num Meth in Ind Forming Processes. NUMIFORM 2007, v. 908, p. 1407-1412.*