ENERGY DISSIPATION AND INSTABILITY PARAMETER AT HIGH TEMPERATURE FORMING OF MIDDLE CARBON STEEL

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Abstract

Deformation characteristics of carbon steel are studied in the temperature range 900 - 1200 °C and strain rates 0.1 - 100 s^{-1} on the plastometr Gleeble using compression tests on cylindrical samples. Processed a single dissipation maps in the field of forming are developed on the basis of changes in the effectiveness of dissipation, depending on temperature and deformation resistance, taking into account the strain rate. Strass-strain curves under different deformation conditions were used. Map of absorption of energy reveals that peak efficiency of strain rate sensitivity parameter is achieved of *m* values of 0.21 and from that the energy dissipation efficiency η is calculated with purpose to find the optimal forming conditions. At the same time to the contour dissipation map, the map of an instability criterion ξ has been added. The instability forming mode is recorded lower values of ξ, in the present case, however, it is not a dramatic slump, only a warning on the possibility of defects. Behavior analysis indicated that there were a dynamic recrystallization at higher temperatures and in all conditions forming since the value 0.2 deformation (deformation at lower strain rates there) and always above 0.2 to 0.4 even at high strain rates.

Keywords: Steel, forming, energy dissipation, instability parameter

1. INTRODUCTION

The first processing map was constructed in 1997 by Prasad et al. [1-3]. Processing maps show on the one hand the areas suitable for forming steels (mainly hard-formable, such as bi-phase, stainless etc.) or non-ferrous alloys (alloys of magnesium, aluminum, nickel, titanium etc.). What is energy dissipation? Some authors say that it is something like effectiveness, but it's not directly it. Because I want to be clear, intimate, so time it as follows. Probably the closest to an explanation of this concept is a distraction of energy. Let's take an example. When forming we need power to change the shape of the body plastic deformation. It doesn't matter if we imagine rolling or pressing or forging, always only part of energy is consumed on the intended change of shape. And so I present to you the concept of disisipation. Total energy *P* which the body absorbs during deformation is comprised of two parts, the first part being energy *G* which represents the input power dissipated by the material, substantial part of which is converted into heat. The second part is the supplement *J* which represents the energy dissipated due to metallurgical changes such as during dynamic recrystallization, dynamic recovery, nucleation, growth of cracks and other processes, and therefore it is the criterion for characterizing the dynamic response of the material. The total energy can be expressed by the following equation [1, 2]:

$$P = G + J \tag{1}$$

where: *P* - total energy absorbed by the body during deformation (J),

G - the energy dissipated due to plastic deformation (J),

J - the energy dissipated due to metallurgical changes (J).

When setting the dissipation of the parameter *m*, which is

$$m = \frac{dJ}{dG} = \frac{\dot{e}\, d\sigma}{\sigma\, d\dot{e}} = \frac{d \ln \sigma}{d \ln \dot{e}} \quad (2)$$

It is widely and generally known that at higher temperatures is less deformation resistence [3]. When we discuss the dozens of up to hundreds of articles about dissipation, so at higher temperatures the numerical value of dissipation are greater. The role here play as well as structure, but for simplicity this proportionality applies.

Less known is that with the influence of strain rate. Again, in most cases, the deformation resistance increases with increasing strain rate. This is reflected in the results of dissipation lower numeric values. Why in most cases it does not take into account the strain rate? Because the real plants, real technological procedure are bound to a specific equipment and say in general, the vast majority of even the technologists in the plants knows very little about what is in their devices, strain rate. If we know the formula for the calculation of values J and J_{max}, we can set a dimensionless parameter η (dissipation efficiency), which is very important for the creation of processing maps. The dissipation efficiency can be the expressed [4-7]:

$$\eta = \frac{J}{Jmax} = \frac{2m}{m+1} \quad (3)$$

Other calculations, it is possible to determine the degree of instability ξ of the forming proces. This math and eventually map dependencies are used in particular for complex structures where they occur at different temperatures and different phase occures, there is a blending of recrystallization and recovery phenomena, precipitation of the inclusions, the elimination phases on the border of the grains and so on. In our steel to prevent examined does not occur and therefore the following images of instability process, are very similar for all deformation, ie 0.2; 0.5 and 0.8. Very little is different for different sizes of deformation, which is obvious from the following pictures.

$$\xi = \frac{\partial \ln\left(\frac{m}{m+1}\right)}{\partial \ln \dot{e}} + m \quad (4)$$

2. EXPERIMENTAL PROCEDURES

Structural carbon steel, microalloyed with boron and titanium, suitable for connecting parts, with very good hot and cold formability and with guaranteed weldability. Directional chemical composition: 0.3 % C - 1.2 % Mn - 0.2 % Si - 0.02 % Ti - 0.003 % B. The compression tests were carried out in the temperature ranges of 900 - 1200 °C and the strain rate ranges of 0.01 - 1 - 10 - 100 s^{-1} on a Gleeble 3800 thermo-mechanical simulator. All specimens were compressed to true strain 1.0, then immediately air cooled down to room temperature. A total of 16 tests were performed. Several passes of the stress-strain curves are shown in the following **Figure 1**.

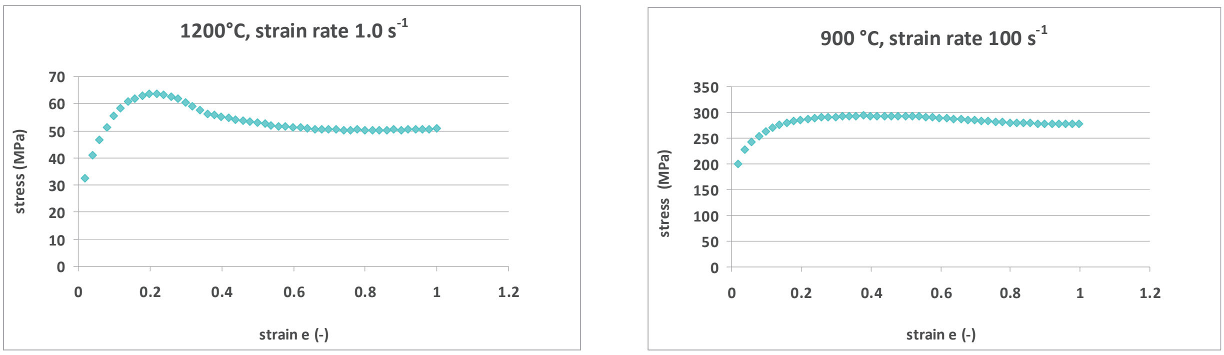
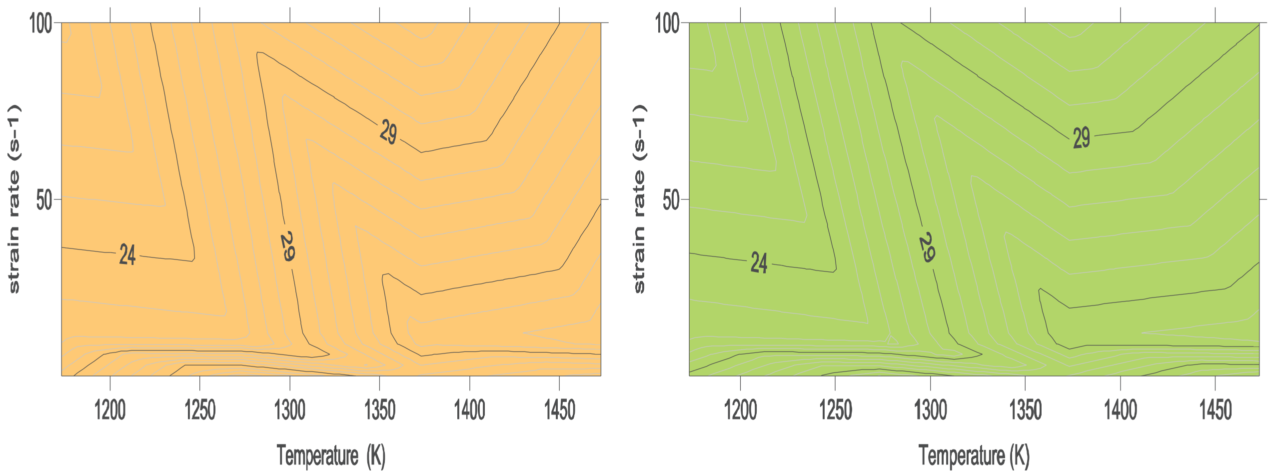


Figure 1 Stress-strain curves

The curves show that at strain rates to 10 s^{-1} is the start of dynamic recrystallization in areas around 0.2 strain. With increasing temperature increases up to 0.4. Conversely, at curves of deformation of 10 and in particular of 100 s^{-1}, the curves resemble the course of dynamic recovery with the steady state of plastic flow, and the peak deformation is shifted to 0.5. Strain rate plays a pivotal role; even at low temperatures, a marked peak with a drop in tension is lost. They indicate that at high temperatures is the beginning of a dynamic recrystallization somewhere around 0.2 deformation at low rates. But even at high temperature and high strain rate the peak becomes less pronounced and moves to the right. This is obviously far more at lower temperatures, where the curve more likely recalls the dynamic progress of recovery to designate after the peak steady-state flow area. The following part of the Excel calculation recount of parameter *m* and gradually from him, then according to the formula the size of the dissipation of the η and instability of ξ.

3. RESULTS AND DISCUSSION

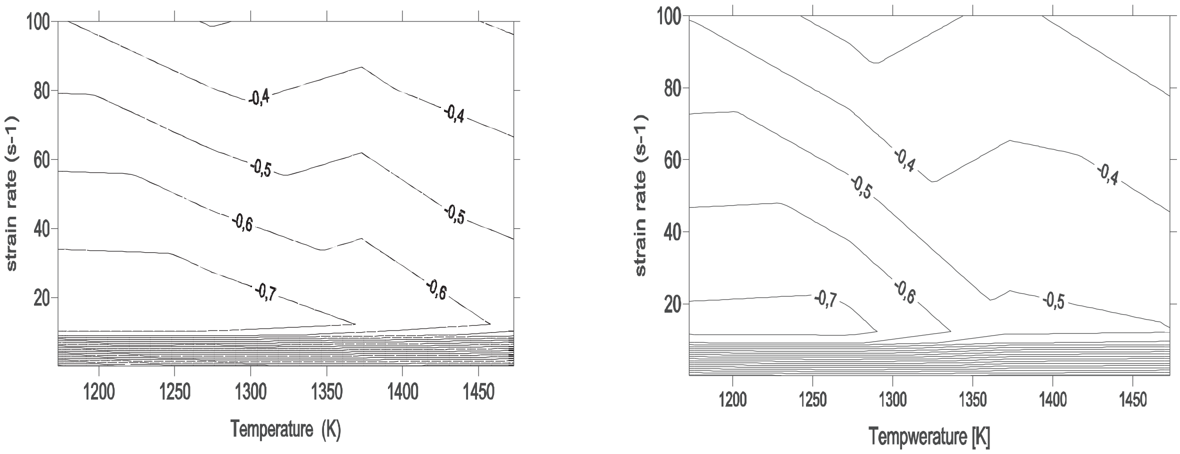
The following images prove it. All other pictures were prepared by program Surfer. The processing maps obtained at strains of 0.2, 0.8 are shown in **Figure 2** (**a**)-(**b**), respectively.



(a) strain = 0.2 (b) strain = 0.8

Figure 2 Dissipation maps

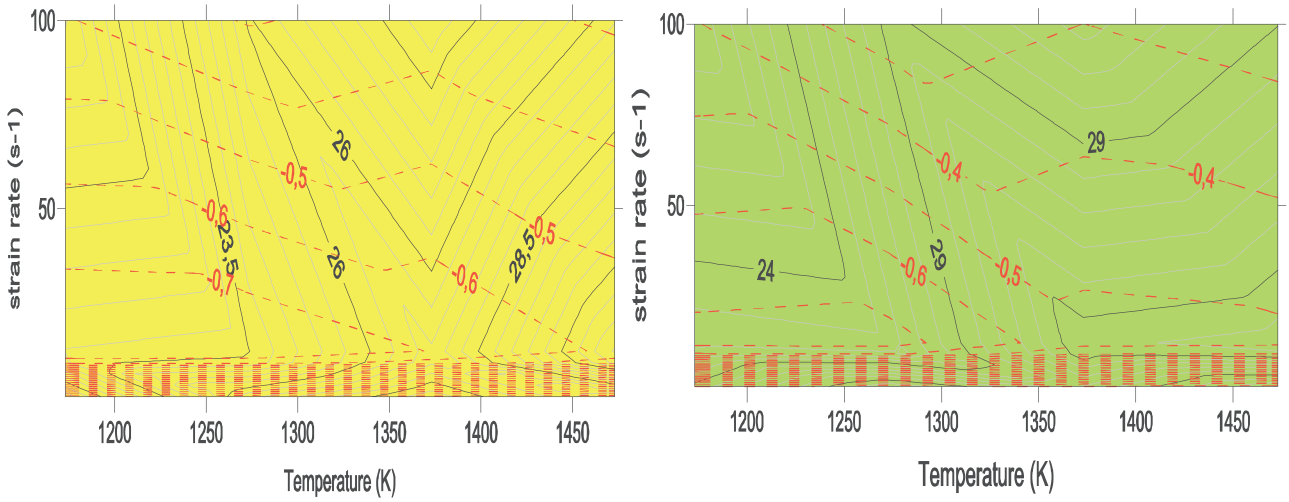
In all figures, the range of strain rates is in a single scale, the minimum value is the deformation velocity of 0.1 s^{-1}, which is not markedly high at the strain rate axis [8]. Typically, logarithmic scales are listed in the literature, the scale chosen for us is more favorable for a direct understanding of the influence of strain rate. However, it has an obvious disadvantage at low strain rates. The contours in the processing maps represent constant efficiency of power dissipation marked as percent. As the temperature rises slightly, the magnitude of the dissipation decreases slightly, as if the peak was negligible at temperatures in the range of 1350 to 1400 K. This is a single map (**Figure 2 (a)**) for deformation 0.2, otherwise the values dissipation η range throughout the range of strain rates from 0.1 to 100 s^{-1} for all deformations in values above 23 % and for all the values of deformations that were examined, ie, the size 0.2 as the mean, then the deformation 0.5 and the highest deformation 0.8. Next we deduced the instability of ξ for all deformations and strain rates. Also, the instability of deformation, expressed by the ξ parameter, is very similar at all deformations. This results from the parameter *m*, which acquires very similar values at low and high velocity deformations. The following figures shows an area of instability for the described strain rates. The values are slightly negative, the more negative, the greater the deformation instability. Distinct and not unexplained are curves in the area of very small deformation where the values exceed the positive number 1.0. From this it can only be assumed that at low strain rates the material is well-formed [9].



(a) strain = 0.2 (b) strain = 0.8

Figure 3 Instability maps

Negative values of parameter ξ are less favorable and may indicate a greater degree of instability (**Figure 3**), and this has not been reflected in our investigated steel. It is, however, that the lowering of the temperature and the lower deformation rates are lower. In terms of instability, for example, with a distortion of 0.5, a spatial image, there is only a slight difference across the temperature range, the instability (positive values) decreases significantly at low strain rates.



(a) strain = 0.2 (b) strain = 0.8

Figure 4 Processing maps

The images represent the loading of two surf maps on top of each other - **Figure 4**. The red dashed lines shows instability, mostly in the range of -0.4 to -0.7 values. The studied steel, essentially basic chemical composition without special increment, with only B content of 0.003 %, behaves naturally and the markedly austenitic character. B does not seem to alter the internal structure. From the graphs of stress-strain curves results from the assessment described in the experiment section. It can also be concluded that higher and more favorable dissipation values are always at lower deformation rates [10].

4. CONCLUSIONS

A simple instability condition was applied to develop the processing maps of examined steel, the domains representing various microstructural mechanisms are explained below:

(1) As the temperature rises slightly, the magnitude of the dissipation increases slightly, as if the peak was negligible at temperatures in the range of 1350 to 1400 K. This is a single spatial map for deformation 0.2, otherwise the values dissipation η range throughout the range of strain rates from 0.1 to 100 s^{-1} for all deformations in values above 23 % and for all the values of deformations that were examined, ie, the size 0.2 as the mean, then the deformation 0.5 and the highest deformation 0.8. At higher temperatures the dissipation run to 34 %. It can also be concluded that higher and more favorable dissipation values are always at lower deformation rates.

(2) Negative values of parameter ξ are less favorable and may indicate a greater degree of instability. However, the tested steel behaves similarly in terms of instability in the entire area of deformation, and it is surprising that, even with low 0.2 strain, the results of both dissipation and instability are little different. From the point of view of mathematics and gradual calculations, this is because the basic parameter *m*, which then calculates the dissipation of η and consequently the instability of ξ, is based numerically very similarly for all the deformation sizes and this has not been reflected in our investigated steel.

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REFERENCES

[1] PRASAD, Y. V. R. K., S. SASIDHARA, S. *Hot Working Guide: Compendium of Processing Maps*, ASM International, 1997.

[2] PRASAD, Y. V. R. K., RAO, K. P. Processing maps for hot deformation of rolled AZ31 magnesium alloy plate: Anisotropy of hot workability. *Materials Science and Engineering A,* 2008, vol. 487, no. 1-2, pp. 316-327.

[3] MOMENI, A. DEHGHANI, K. Hot working behavior of 2205 austenite-ferrite duplex stainless steel characterized by constitutive equations and processing maps. Materials Science And Engineering A, 2011, vol. 528, no. 3, pp. 1448-1454.

[4] KAI Wu, GUOQUAN Liu, BENFU Hu, FENG Li, YIWEN Zhang, YU Tao, JIANTAO Liu. Characterization of hot deformation behavior of a new Ni-Cr-Co based P/M superalloy. Mate rials characterization 61 (2010) 330 - 340. Srinivasan, N.; Prasad, Y. V. R. K.; Rao, P. Rama. Hot deformation behaviour of Mg-3Al alloy - A study using processing map. Materials Science And Engineering A 476 (2008) 146-156.

[5] GUOLIANG Ji, FUGUO Li, QINGHUA Li, HUIQU Lib, ZHI Li. Development and validation of a processing map for Aermet100 steel. *Materials Science and Engineering* A 527 (2010) 1165-1171.

[6] JI, G., et al. Development and validation of a processing map for Aermet100 steel. *Materials Science and Engineering A*, 2010, vol. 527, no. 4-5, pp. 1165-1171.

[7] NING, Y., et al. Investigation on hot deformation behavior of P/M Ni-base superalloy FGH96 by using processing maps. *Materials Science and Engineering A*, 2010, vol. 527, no. 26, pp. 6794-6799.

[8] KUBINA, T., KLIBER, J., KUNČICKÁ, L. Plotting of Processing Maps of P91 Steel and Ms70 Brass with Energy Dissipation and Instability Parameter Computation on the basis of Plastometric Tests. In: *Metal 2013*, Conference Proceedings. Ostrava: Tanger Ltd, 2013, pp. 456-460. ISBN 978-80-87294-41-3.

[9] WU, K., et al. Characterization of hot deformation behavior of a new Ni-Cr-Co based P/M superalloy. *Materials Characterization*, 2010, vol. 61, no. 3, pp. 330 - 340.

[10] KLIBER, J., POKLUDA, T. Processing map of 9 % chromium steel P91. *Metal Forming*, 2016, vol. 27, no. 3, pp. 179-194.