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Influence of hot-working conditions on a structure of high-manganese austenitic steels

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Properties

ABSTRACT

Purpose: The aim of the paper is to determine the influence of hot deformation conditions on σ-ε curves and structure changes of new-developed high-manganese austenitic steels.
Design/methodology/approach: The force-energetic parameters of hot-working were determined in hot-compression tests performed in a temperature range of 850 to 1050°C by the use of the Gleeble 3800 thermomechanical simulator. Evaluation of processes controlling work hardening at 850°C were identified by microstructure observations of the specimens water-quenched after plastic deformation to a true strain equal 0.22, 0.51 and 0.92.
Findings: At initial state the steel containing 3% of Si and Al possesses homogeneous austenite structure with many annealing twins. Increased up to 4% Si concentration and decreased to 2% Al concentration result in a presence of some fraction of ε martensite plates. For applied deformation conditions, the values of flow stress vary from 250 to 450MPa – increasing with decreasing deformation temperature. A relatively small values of ε_{max} deformation at temperatures of 1050 and 950°C allow to suppose that in this range of temperature, to form a fine-grained microstructure of steels, dynamic recrystallization can be used. At a temperature of 850°C, the dynamic recrystallization leads to structure refinement after true strain of about 0.51.
Research limitations/implications: To determine in detail the hot-working behaviour of developed steels, a progress of recrystallization as a function of time at deformation temperature should be investigated.
Practical implications: The obtained stress-strain curves can be useful in determination of power-force parameters of hot-rolling of high-manganese austenitic steels.
Originality/value: The hot-working behaviour of new-devoloped high-manganese austenitic steels containing Nb and Ti microadditions was investigated.
Keywords: Metallic alloys; High-manganese steels; Hot-working; Dynamic recrystallization; Metadynamic recrystallization.

1. Introduction

During last thirty years, numerous new groups of steels have been elaborated finding their application in automotive industry. These are IF- (Interstitial Free), BH- (Bake Hardening), IS- (Isotropic), DP- (Dual Phase), TRIP- (TRansformation Induced Plasticity), CP- (Complex Phase) and TMS- (Martensitic) steels [1-4]. They possess a very wide combination of strength and ductile properties and can be used for different elements of autobody. Particularly profitable combination of these properties and especially possibilities to absorb high values of energy during crash-events have TRIP-type sheets. This feature is due to a multiphase structure consisting of ferrite, bainite and retained austenite [5-7]. The strain-induced transformation of the γ phase into martensite during technological forming contributes to high strength and plasticity of finish products. This behaviour is well known as TRIP (Transformation Induced Plasticity) [7,8].

Demands connecting with passive safety improvement of cars and manufacturing elements with a complicated shape are a reason of searching new materials, showing these characteristics. New possibilities appeared at the beginning of this century, when the effect of strain-induced martensitic transformation of γ phase was attempted to be applied in austenitic steels. This effect was used many years ago but for expensive Cr-Ni steels. Nowadays, new group of high-manganese austenitic steels with variable concentration of Mn, Al and Si is a subject of investigations [9-11]. High-manganese austenitic steels consist of 15 to 30% of Mn, from 0.02 to 0.2% of C and around 2-4% of Al and Si. The role of Si and Al is solution hardening of the steel and carbon is an element that stabilizes austenite. These steels achieve UTS=600÷900 MPa, $YS_{0.2}$=250÷450 MPa, UEl = 30÷80%, which depend especially on concentration of Mn [12,13].

Published so far results of researches relate in large majority to high-manganese steels in supersaturated state. Processes occurring during hot-working and their influence on microstructure evolution should be also taken into account. Obtaining the fine-grained structure of steel sheets before solution heat treatment is possible by controlling recovery and recrystallization processes occuring during hot-working. In order to develop the manufacturing methods, it is important to determine the flow behaviour of steels under hot-working conditions. Several works concern the behaviour of Fe-Cr-Mn, Fe-Mn and Fe-Mn-Al steels during plastic deformation [14,15]. However, there is no information regarding high-manganese steels containing silicon and microadditions. Their application can also contribute to mechanical properties increase, likewise in case of multiphase steels [5,6].

2. Experimental procedure

The investigations were carried out on high-manganese steels with a chemical composition given in Table 1. The melts were done in Balzers VSG-50 vacuum induction furnace. Liquid metal was cast into moulds in argon atmosphere. Obtained 25 kg ingots were subjected to open die forging to 220 mm wide and 20 mm thick flats, from which cylindrical ∅10x12mm samples were made.

In order to determine σ-ε curves high-temperature compression tests in the temperature of 850, 950 and 1050°C with $10s^{-1}$ strain rate were performed. Work-hardening curves were assigned using DSI Gleeble 3800 thermomechanical simulator. The specimens were inserted in a vacuum chamber, where they were resistance-heated. Tantalum foils were used to prevent sticking and graphite foils as a lubricant. The evaluation of processes controlling the course of work-hardening was done through microstructure freezing of samples deformed in the temperature of 850°C, to the engineering strain equal 20, 40 and 60%, respectively.

Table 1.
Chemical composition of the investigated steels

Mass contents, (%)							
C	Mn	Si	Al	P	S	Nb	Ti
Designation		27Mn-4Si-2Al-Nb-Ti					
0.040	27.5	4.18	1.96	0.002	0.017	0.033	0.009
Designation		26Mn-3Si-3Al-Nb-Ti					
0.065	26.0	3.08	2.87	0.004	0.013	0.034	0.009

Metallographic tests of samples along with the determination of grain size were performed on LEICA MEF4A optical microscope. In order to reveal the austenitic structure, samples were etched in nitric and hydrochloric acids mixture in 2:1 proportion as well using a mixture of nitric acid, hydrochloric acid and water in 2:2:1 proportion.

3. Results and discussion

Elaborated steels are characterized by different microstructure in the initial state. The 27Mn-4Si-2Al steel has austenite matrix with grain size of approximately 100μm with annealing twins (Fig. 1). Parallel lines present in some of the grains indicate the presence of ε martensite, formed during cooling of the steel. The 26Mn-3Si-3Al steel has homogeneous microstructure of austenite with similar grain sizes, containing also annealing twins (Fig. 2). Taking into consideration similar concentration of C, Mn, Nb and Ti, the presence of ε martensite in the first steel should be explained by increased concentration of Si and decreased concentration of Al when comparing to 26Mn-3Si-3Al steel.

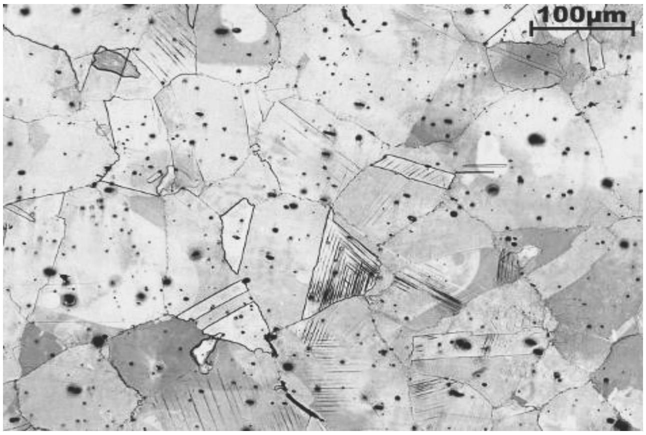


Fig. 1. Austenitic structure of the 27Mn-4Si-2Al steel containing ε martensite plates and annealing twins

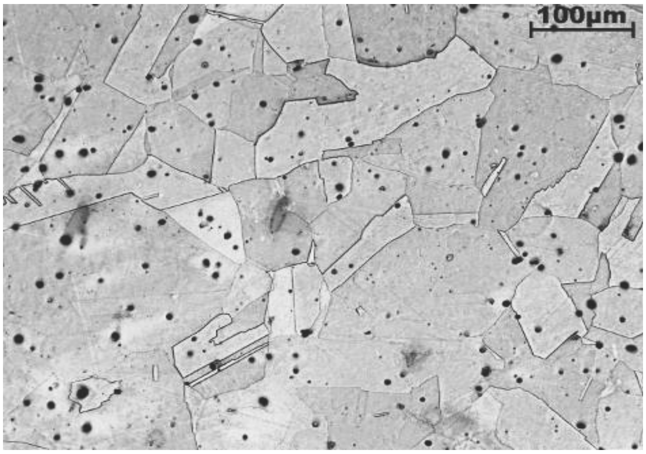


Fig. 2. Austenitic structure of the 26Mn-3Si-3Al steel containing annealing twins and non-metallic inclusions

The flow curves presented in Fig. 3a are helpful in estimation of power-force parameters of hot-working as well as in evaluation of processes controlling strain hardening. They allow concluding that deformation of 27Mn-4Si-2Al steel in a temperature range of 1050-850°C requires high values of flow stress equal from 250 to 450MPa. These values are considerably higher than they are for constructional microalloyed steels [3,4] and for Cr-Ni-Mn austenitic steels [14], as well as for Mn-Al steels [15]. It's probably a result of strong strengthening influence of silicon and also due to the presence of Nb and Ti microadditions. A way to decrease the value of flow stress is application of reduction higher than ε_{max} – corresponding to 0.23, 0.32 and 0.5 of true deformation – for 1050, 950 and 850°C deformation temperatures, respectively. In the industrial conditions, it's possible only in first roll passes realized in a temperature range up to around 950°C. Decrease of flow stress is connected to the course of dynamic recrystallization during hot plastic deformation. However, plastic deformation with 20% is too low to initiate dynamic recrystallization (Fig. 3b), what is in agreement with a curve course in Fig. 3a. Increase of true deformation to 0.51 corresponding to ε_{max} results in the presence of fine recrystallized grains arranged on the boundaries of dynamically recovered grains (Fig. 3c). Further increase of true deformation to 0.92 leads to formation of ultra-fine-grained microstructure of homogeneous dynamically recrystallized grains (Fig. 3d).

Slight differences in chemical composition of elaborated steels cause that in a temperature range from 1050 to 950°C steel 26Mn-3Si-3Al has practically identical course of σ-ε curves (Fig. 4a). The steel possesses only slightly lower values of flow stress for the deformation temperature of 850°C deriving probably from lower concentration of Si when comparing to 27Mn-4Si-2Al steel. The steel microstructure in conditions initiating a dynamic recrystallization is presented in Fig. 4b. The processes controlling the course of strain hardening for successive reductions are identical as for 27Mn-4Si-2Al steel.

In case of final roll passes, when applied deformation can be too low for refinement of microstructure as a result of dynamic recrystallization – processes removing strain hardening during intervals between passes can have essential meaning. It will be a subject of further investigations.

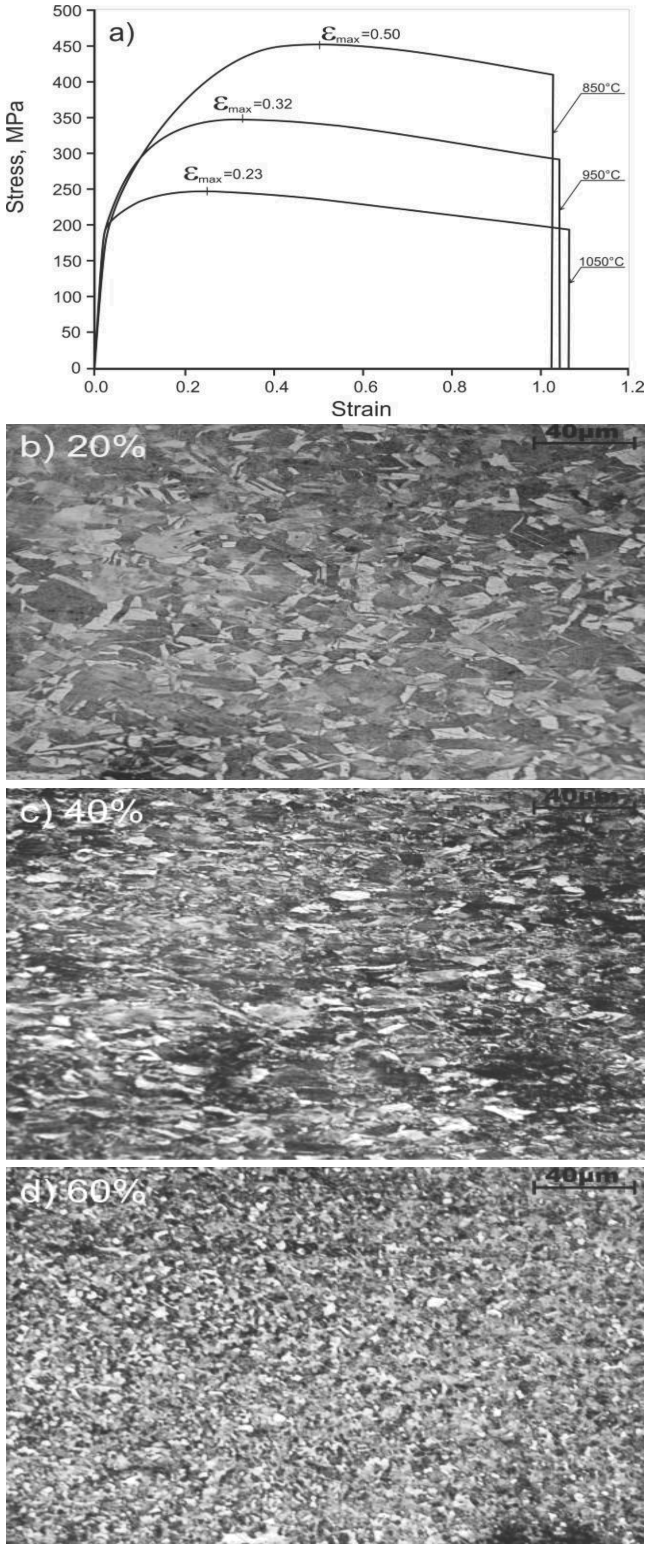
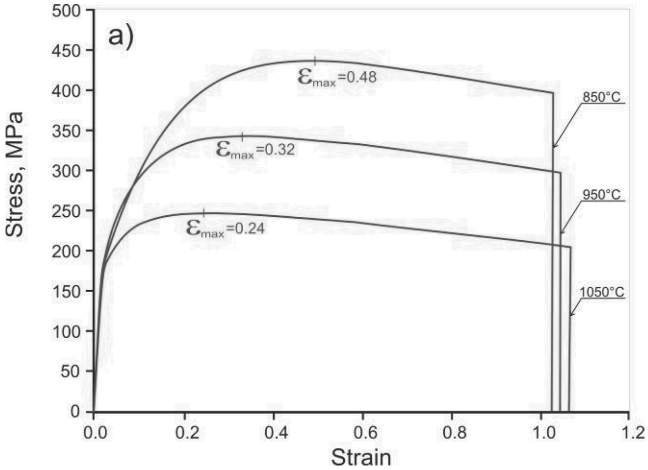


Fig. 3. Stress-strain curves of the 27Mn-4Si-2Al steel – (a), and austenitic structures of the specimens solution heat-treated from 850°C after deformation 20% (b), 40% (c) and 60% (d)



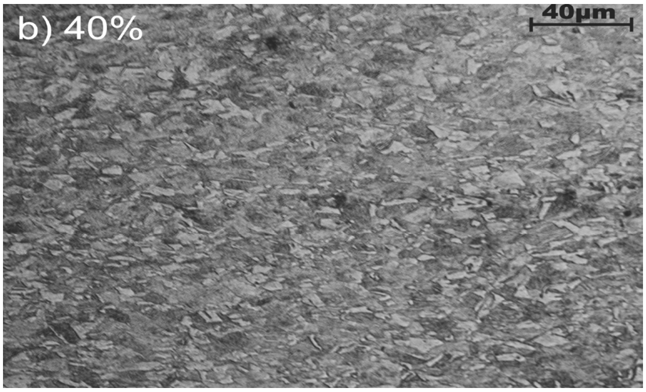


Fig. 4. Stress-strain curves of the 26Mn-3Si-3Al steel – (a), and austenitic structure of the specimen solution heat-treated from 850°C after deformation 40% (b)

4. Conclusions

Slight differences in chemical composition of the investigated steels are a reason of some differences in initial structures. Steel containing 3% of silicon and aluminium is characterized by homogeneous austenite structure with many annealing twins. Increased up to 4% silicon concentration and decreased to 2% aluminium concentration result in a presence of some fraction of ε martensite plates. However, initial structure differences have no influence on hot-working behaviour of the new-developed steels. The stress-strain curves have a very similar course. For applied deformation conditions, the values of flow stress vary from 250 to 450MPa – increasing with decreasing deformation temperature. These values are essentially higher compared to conventional carbon-manganese and microalloyed steels. It is connected with strengthening influence of Mn, Si and Al dissolved in a solid solution. However, a relatively small values of ε_{max} deformation at temperatures of 1050 and 950°C allow to suppose that in this range of temperature, to form a fine-grained microstructure of steels, dynamic recrystallization can be used. At a temperature of 850°C, the dynamic recrystallization leads to structure refinement after true strain of about 0.5.

Acknowledgements

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