Gradus Vol 4, No 2 (2017) 426-431
ISSN 2064-8014

SURVEY ON STEEL STRENGHTENING METODS

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Keywords:
high strength steels
ultrafine grained steels
micro-alloyed steel
precipitation strengthening

Article history:
Beérkezett: 2 November 2017
Átdolgozva: 2 November 2017
Elfogadva: 2 November 2017

Abstract
During the last ten years, enormous research activity had been carried out to increase the strength properties of engineering materials. Steels are widely used in heavy stressed constructions such as bridges, cranes or different supports in vehicles. In these applications, low carbon low alloyed steels can be used in order to ensure further processing by welding or cold forming. The purpose of this paper is to give an overview about novel technics applied in steel production to obtain high strength steels.

1 Introduction

Producing of high strength steels with high toughness is a great challenge for steel industries. To maintain steel products at a low cost or even reduce costs and increase strength novel techniques had been applied in course of different research projects that focused on implementing new mechanisms in steel production related to grain size refinement, precipitation hardening, changing the morphology of the precipitates, or developing new microstructure combinations by applying new heat treatment processes, or combining heat treatment with forming, rather than using expensive alloying elements. High strength steel is attributed to steel with higher tensile strength than 1000 MPa and ultra-high strength up to 2000 MPa. The grain sizes of steels produced through common thermo-mechanical processes are in the range of 5-10 µm in diameter. Some papers referred to ultrafine grained steels with grain sizes of about 1 µm, submicron between 100 and 1000 nm, and nanostructured below 100 nm [1].

2 The effect of composition on mechanical properties

It is known that increasing the amount of carbon and alloying elements in steels results in increase of strength but lowers ductility and toughness. This has a negative impact during the further processing of steel sheets by plastic deformation and is critical when high deformability is needed for example in the case of shaping car body panels. Sheet metals for deep drawing used in car industry are of two different types, i.e. steels with tensile strength TS=270 – 410 MPa (DC 03-DC 06 series, MSZ EN 10130) that have almost ferritic microstructure with a small amount of pearlite and steels with higher strength TS= 450-780 MPa (e.g. DP – dual phase steels), which have ferritic-martensitic microstructure. In this latest case the carbon content and the alloying elements are kept at low values: e.g. 0.08-0.1 % C; 0.15-0.2 % Si; 0.7-1 % Mn; ~0.03 % Cr; ~0.03 % Ni; ~0.01 % Nb; ~0.01 % V. In PD 600 (TS ~600 MPa, A_{80} ~20%) the increase in strength is due to the hard martensitic phase, and the deformability is ensured by the soft ferritic matrix. The microstructure of this steel is shown in Figure 1. By increasing the amount of martensite in the microstructure higher tensile strength values can be obtained (up to 1000 MPa) with decrease in ductility. In the case of further processing of these steels by welding, again the composition should be adequate in order to not appear hard phases (e.g. martensite, bainite) in the heat affected zone, otherwise care must be taken during welding, which can increase the costs of welding.

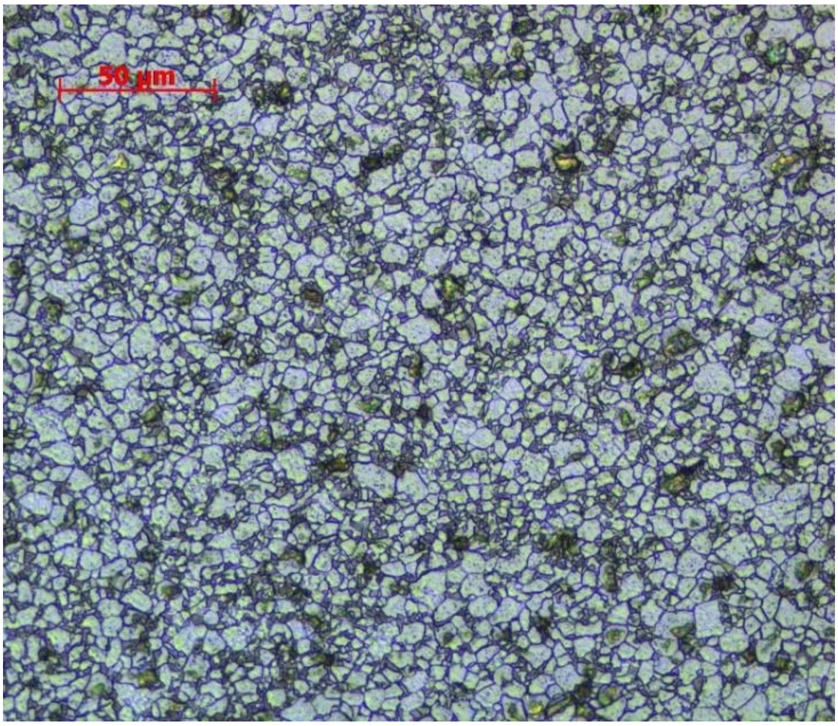

Figure 1. Microstructure of a DP 600 steel

For this reason, carbon content should be kept below 0.2 % at around 0.1 % and the total amount of alloying element should be below 1 % except of manganese, that increases both strength and ductility if it is present below 1.6 %.

Thus, setting only the composition cannot be produced steels with high strength and adequate toughness, therefore research activities have focused on different techniques that increase strength without decreasing toughness.

3 The effect of second phase precipitation on mechanical properties

Ti, Nb, V, Mo are used as micro-alloying elements in steel. These elements are present in small amounts (less than 0.1 %) and can precipitate as fine carbide during thermo-mechanical processing of steel products.

In the last ten years thermo-mechanical processing had been widely studied in order to determine the microstructural changes that lead to strength increasing of steel. A high strength low alloy steel with composition of 0.08 % C, 0.2 % Si, 1.52 % Mn, 0.085 % Ti, 0.035 % Nb, and 0.11 % Mo was thermo-mechanically processed according to the Figure 2. The micro-hardness was determined after applying different cooling rates from 850°C to 600°C [2].

The resultant microstructure was polygonal ferrite with a small amount of lath-type bainite in specimens subjected to 1°C/s and 5°C/s cooling rate. With the increase in cooling rate there was an increased tendency towards formation of lath-type bainitic ferrite [2]. The results of the micro-hardness measurements of individually ferrite grains shows that with increasing cooling rate the average micro-hardness decreases. This can be attributed to precipitation hardening of fine random (Figure 3.) or interphase precipitates that could precipitate during lower cooling rate. The fine precipitates of size range 6-10 nm were MC (metal-carbide) type of (Ti,Nb,Mo)C. [2].

These results show that not only fast cooling can cause increase in hardness due to increase in internal stresses, but an adequate lower cooling rate to an adequate temperature where second phase precipitation can occur can lead to even higher hardness values and probably less distortion because of the dispersed arrangement of the fine precipitates.

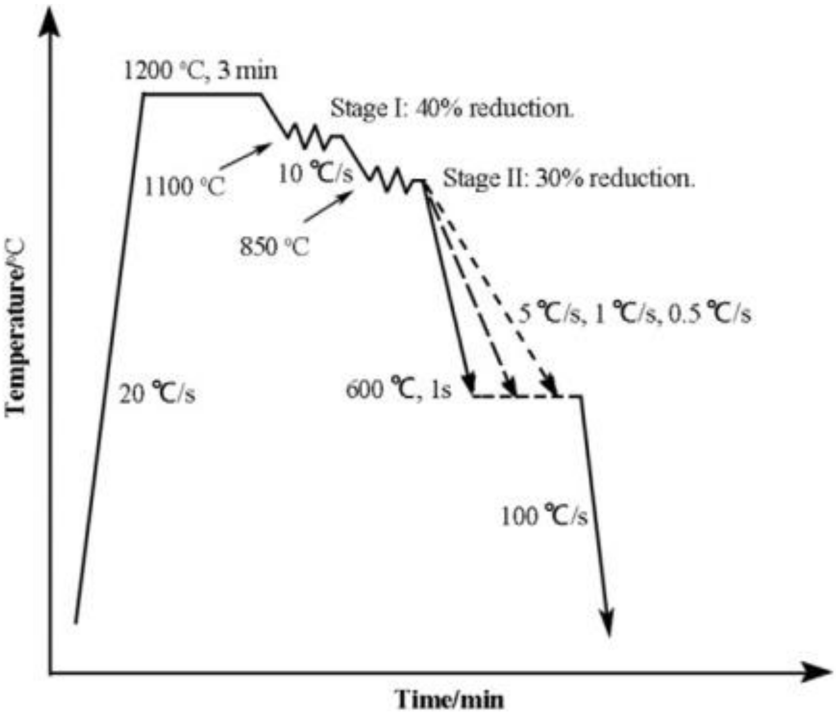

Figure 2. Schematic diagram of controlled rolling sequence [2]

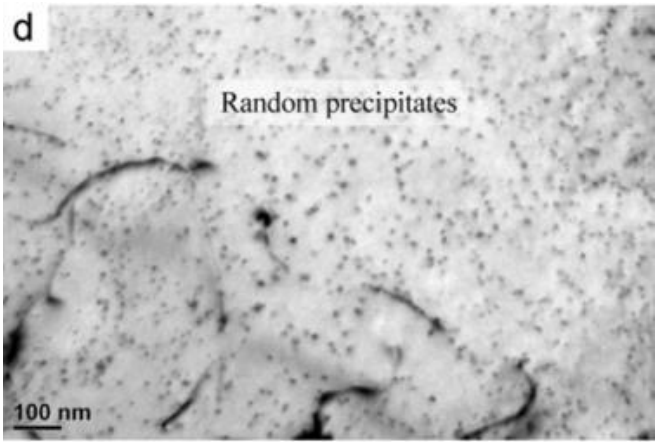

Figure 3. Bright filed TEM micrographs observed from thin foils showing random precipitates in the ferrite matrix of Ti micro-alloyed steel processed at low (or intermediate) cooling rate [2]

A new technique to develop advanced steels with superior mechanical properties can be based on co-precipitation of fine nanoparticles. The co-precipitation of multiple types of nanoparticles can be more effective than precipitation of a single type of nanoparticles resulting from the combination of the different properties of these materials. Nanoparticles that satisfy the lattice coherency requirement with the bbc-Fe matrix are suitable for co-precipitation hardening of steels.

As an example, the main constituents of this kind of steel can have the following composition: 0.05 % C, 3 % Cu, 4 % Ni, 3 % Mn, 1.4 % Al. In course of aging of this alloy NiAl and Cu nanoparticles can precipitate forming Cu/NiAl co-precipitates with diameters 1-5-10 nm depending on the amount of Ni and Al [3]. A possible arrangement of this particles is shown in Figure 4.

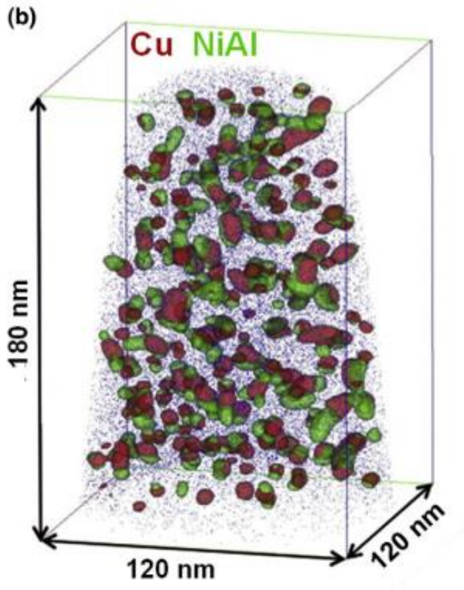

Figure 4. Co-precipitation of Cu and NiAl particles in steel [3]

4 The effect of iron-carbide morphology on mechanical properties

In case of structural components subjected to high loads that should withstand dynamic loads beside high strength high toughness is also needed. Structural steels for beams can be manufactured from micro-alloyed steels. The increase in toughness of these steels has been examined on two steels (0.03-0.1 % C, 0.5-1.5 % Mn, 0.15-0.25 % Si) with different micro-alloying elements: 0.02-0.05 % Nb, and V respectively [4]. The microstructure of steels with such low carbon content consist mainly of ferrite with lower amount of pearlite. The iron carbide lamellae in pearlite is formed by diffusion of carbon to the austenite grain boundary, and will be surrounded by ferrite at the end of transformation during slow cooling (equilibrium).

During processing by controlled rolling non-equilibrium conditions are present. It was found in the case of the above mentioned steels that when the transformation temperature was between normal pearlite and upper bainite instead of continuous lamellae, fragmented iron carbide lamellae appeared in α solid solution, which is called degenerated pearlite. This morphology can result from the insufficient carbon diffusion due to lower temperatures to form continuous lamellae. One possible mechanism that has led to apparition of degenerated pearlite is shown in Figure 5.

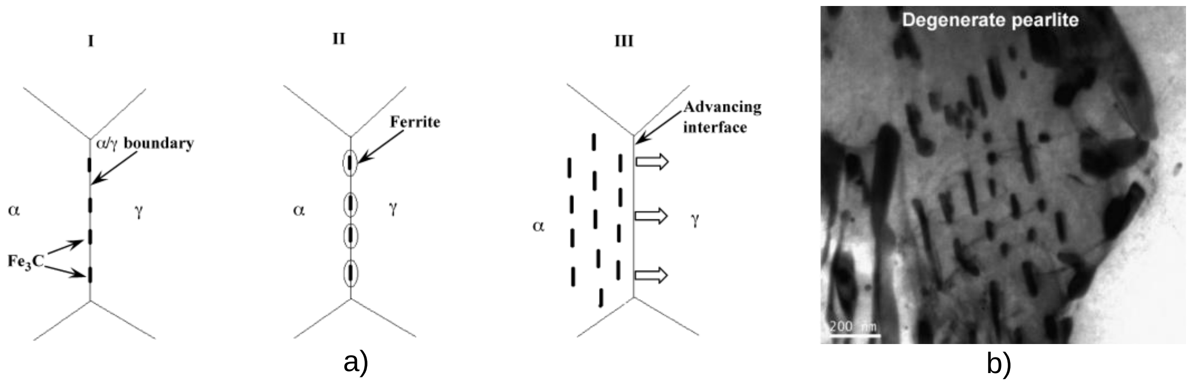

Figure 5. Schematic diagram illustrating the formation mechanism of degenerated pearlite (a); Bright field TEM micrograph showing degenerated pearlite in steel (b) [4]

In this case with increasing cooling rate the amount of degenerated pearlite was increasing and this was attributed to the increase in toughness of the steels processed with higher cooling rate [4].

5 The effect of grain size on mechanical properties

High strength and high toughness can be also achieved by producing ultrafine grained steels with grain sizes below about 1 μm. Advanced thermomechanical processes based on different mechanisms such as:

- dynamic recrystallization of austenite during hot deformation followed by γ (austenite)→α (ferrite) transformation;
- strain-induced ferrite transformation (transformation during deformation);
- hot rolling in the austenite-ferrite two phase region;
- dynamic recrystallization of the ferrite during warm rolling;
- cold rolling and annealing of a martensitic starting microstructure;

and severe plastic deformation at room temperature or at warm deformation temperature can ensure a submicron grain structure [1]. Figure 6. shows the mechanical properties of a 0.2 % C steel with different grain sizes that where produced by the conventional route (without large strain warm deformation), and warm deformation procedure with four steps followed by annealing [1]. Higher strength (tensile strength above 600 MPa) and still good ductility (20 % total elongation) can be achieved in ultrafine grained steel. The ductile-to-brittle transition temperature (DBTT) decreases because of the grain refinement.

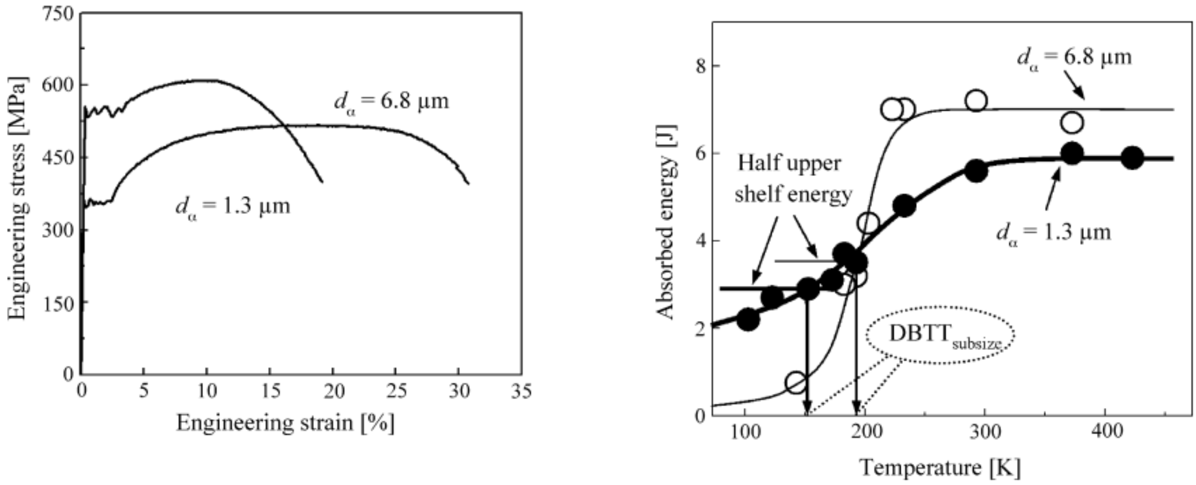

Figure 6. Mechanical properties of steels with different grain sizes [1]

6 Summary

This survey focused on presenting new research results related to novel strengthening techniques applied for low carbon steels. These techniques involve developments in the field of steel production like choosing the right composition (carbon content and micro-alloying elements) as well as developments in the further processing technologies such as rolling, and heat treatment or combining these in order to achieve different microstructure, phase morphology and grain size, that ensures increased strength properties without decreasing toughness and deformability of the steel.

Acknowledgment

This research was supported by EFOP-3.6.1-16-2016-00006 "The development and enhancement of the research potential at John von Neumann University" project. The Project is supported by the Hungarian Government and co-financed by the European Social Fund.

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