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To cite this article: I Ilca et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 477 012003

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Study on the quality of Boron micro–alloyed steels destined to applications in the automotive sector

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Abstract. The paper presents a study of the possibilities of using 20MnB5q the Boron micro–alloyed steel in the assembly of the body components. It is investigated whether the steel in question can be deformed without being globulised but only chilled in flux, followed by a normalization treatment, in order to obtain a finer structure with a globulising tendency. The research has been carried out on samples of 20MnB5q indigenous steel, compared with samples from bars imported from the same French and Finnish origin. Finally there are specified the structural and qualitative differences for this micro–alloyed Boron steel, which in addition to the finishing effect of the structure, have contributed to the increase of the mechanical characteristics. This study examines the behaviour of 20MnB5q grade steel in the manufacturing process of assembly components. The effect of trace Boron in steels, especially the influence of Boron on microstructure and properties of these steels were summarized.

1. Introduction

Improving the safety of structures under specific service conditions has been the driving force for intensive research in the area of high strength steels. Therefore, in addition to producing steel with the required mechanical properties (strength, toughness), it is increasingly necessary to satisfy processing requirements like weldability, machinability, corrosion resistance, and more.[1], [2] To achieve improved mechanical properties and in the same time excellent weldability, it was necessary to produce an extra–low carbon steel with single phase of fine bainitic ferrite microstructure.[1], [3] This has been achieved by the addition of the elements for hardenability and thermo–mechanical controlled process and, therefore, addition of Boron plays an important role in increasing remarkably the hardenability of steel. Consequently, the effect of Boron content in steels and effect of heat treatment on mechanical and metallurgical properties of their has been investigated by various researchers.[1– 20] Researchers have been paying attention to the Boron effect in steels for a long time due to its potential to increase the steel hardenability. However, the mechanism by which Boron increases the hardenability is not completely clear. At present, there are just a few studies strictly focused on the Boron effect on the hot ductility of steels, although the Boron segregation and its effect on austenitic grain boundary play an important role during high temperature deformation and dynamic recrystallization.[18] Mostly, the effect of Boron micro–alloying on the structural transformations, hardenability, and mechanical properties of building steel alloyed with Chromium, Manganese, Molybdenum, Vanadium, and Titanium are considered.[8], [9], [12], [16], [20] Also, the conditions of melting of Boron–bearing steel with most effective recovery of Boron are analysed.[9], [12], [19], [20]
The development of structural steels that can meet all requirements together with reasonably low costs of production is an eternal challenge.[1–8] Advanced structural steels used nowadays are high strength, micro–alloyed steels, obtained by means of a suitable combination of chemical composition and thermo–mechanical treatment parameters in order to have a correct balance between strength, toughness and weldability.[1], [2] Due to a steadily rising vehicle safety and crash requirements in the automotive industry, the use of high–strength steels in structural and safety components is rapidly increasing. The higher requirements for vehicle crash performance can be achieved only by using thick–gauge steel, which results in weight increase.[6–8] Therefore, the high–strength steels, like Boron alloy steels, which meet automotive safety and crash requirements, are being used increasingly in a number of end product applications in the automotive sector. In this sense, hot–forming of the quenchable Boron–alloy steels can produce several complex, crash–resistant structural parts such as front and rear bumper beams, door beams and pillars, with ultrahigh strength and reduced sheet thickness.[6–8]

Boron alloy steels are still under development and experience will show the applications for which they will have specific benefits.[5–10] Boron steels, ideal after heat treatment at high hardness values have reached, also the friction and wear very good resistance against which they often harsh working conditions are suitable for a variety of applications, as a wear material and as a high strength structural steels, and are of particular interest in the field of quality and the technical performances to be achieved. Extreme demands are imposed on the steel when machines and their components are exposed to high, dynamic stresses.[5–10] High–strength steels enable engineers to design lighter, higher–performance structures, offering good overall cost–effectiveness, lower fabrication costs and increased safety. The high–performance steels are recommendable whenever the steel is subject to extraordinary requirements, such as maximum purity, surface hardness and fatigue strength. The composition of these steels, therefore, was based on as low a carbon content, but exactly adjusting the entire chemical composition, must achieve optimum processing and service properties, made–to–measure for every application.[5–10]

Carbon–Manganese–Boron steels are generally specified as replacements for alloy steels for reasons of cost, these steels being far less expensive than alloy steels of equivalent hardenability.[1–8] Boron over 8 ppm the content is considered as an alloying element and it is dissolved in ppm quantities in solid state in steel.[2], [3], [9], [10] Recent research has highlighted the strong action on the feasibility of adding a few tenths of a thousandth of a percent of Boron.[1–20] It is well–known that a small amount of Boron dramatically increases the hardenability of steels, the basic effect of Boron in the steel being the enhancement of hardenability, which is evident already at a very small concentration, of the degree of 20ppm Boron.[8], [9], [11–14] This beneficial effect is attributed to grain boundary segregation previously mentioned, which retards the diffusional transformation of austenite to ferrite by lowering the interfacial energy at the austenite grain boundary.[15], [16] Therefore, Boron in steel in very low quantities (0.001–0.003) greatly increases hardness and strength, and also the hardenability of low carbon steels. With increasing addition of Boron to the extent of about 20ppm, both the tensile strength and hardness values increase, attributed to carbide forming tendency of the Boron.[17] Moreover, Boron have similar effect to those obtained with such common alloying elements as Manganese, Chromium, Nickel, and Molybdenum, but, unlike these elements, only a minute amount of Boron is required. Even in the small quantity of the degree of size up to 40 ppm, Boron gives the same effect of the hardenability enhancement as other more expensive elements which must be added in much bigger quantity.[9], [11]

The action of Boron is effective during quenching for low carbon steels, and when annealing is null. The Boron additive steels, easy to be processed and applied in very good mechanical properties after heat treatment are important features exhibitions. According to the same mechanical properties are cheaper than high alloy steels. In addition to the benefits of economy and alloy conservation, Boron steels offer significant advantages of better machinability compared with Boron free steels of equivalent hardenability.[20] Moreover, steels containing Boron are also less susceptible to quench cracking and distortion during heat treatment. Consequently, Boron containing Carbon alloy steels are
widely used in automotive, constructional, and various other applications, including agricultural machinery and tools (discs, plough shares), public works machinery, mining, cutting equipment, safety beams in vehicles or concrete mixer drums, due to the several important advantages such:

— suitable for environmentally–friendly water quenching processes;
— excellent hardening performance, also possible with both oil and gas quenching;
— high wear and abrasion resistance – meaning more durability, less material weight loss, low maintenance level, longer lifetime and increased cost savings; and
— heat treatable Boron steel grades offer excellent resistance against abrasive wear.

Consequently, the Boron steel grades represent a breakthrough for durable steel – meaning they are a cost–effective solution to prolong the lifetime of your final products. Hardened via a Boron quenching process and hot rolling–controlled thermo–mechanical treatment, the Boron steels offers a remarkable degree of hardness, giving the final product:

— a uniform microstructure;
— outstanding mechanical loading; and
— excellent resistance to abrasive wear.

2. Boron micro–alloyed steels

Boron micro–alloyed steels are classified as low–alloy high–strength steels which are classified by their mechanical properties and especially their flow limit. These steels grades are: OLC15q, OLC35q, OLC45q and 20MnB5q. In addition, other steel grades are also used. To produce such a microstructure especially with a low–carbon micro–alloyed steel, the chemical composition had to be designed very carefully. The basic alloying system contains Nickel, Chromium, Molybdenum and the micro–alloying elements Vanadium, Niobium, and Titanium. Besides these the micro–alloying element Boron should also be effective.

Steel grade 26MnB5q, in accordance with [21], is one of the Boron–alloyed quenched and tempered steels. This grade is characterized in particular by their formability in the hot rolled state and their high strength after the heat treatment process, where the addition of Boron leads to the strain hardenability of this Carbon–Manganese–Chromium alloy. In fact, the strength characteristics after quenching and tempering are achieved in particular by the low Boron content, in addition to the Carbon and Manganese. This grade features homogeneous material properties that enable consistent and predictable performance of the final component. The material is very clean, meaning the levels of impurities are carefully controlled, which helps with consistency in formability and weldability. In Table 1, the recently established standard for 20MnB5q steel is presented.[21] Boron alloy steels are specified when the base composition meets mechanical property requirements (toughness, wear resistance, etc.), but hardenability is insufficient for the intended section size. Rather than call for a more highly alloyed and therefore more expensive steel, a user may simply specify the corresponding Boron grade, thereby ensuring suitable hardenability.

| Yield Rp0.2 (MPa) | Tensile Rm (MPa) | Elongation A (%) | Reduction in cross section on fracture Z (%) | Brinell hardness (HBW) |
|------------------|-----------------|-----------------|-------------------------------------------|------------------------|
| 700 (≥)          | 900–1050        | 14              | 55                                        | 255–270                |

The transformation of austenite in the quality carbon steels is almost entirely determined by the Carbon and Manganese content. The Manganese content is chosen so as to obtain the desired microstructure and properties, the chosen Carbon content and the given cooling conditions.[1–5] The

| The chemical composition [%] |
|-----------------------------|
| C  | Si | Mn | P  | S  | B  |
| 0.17–0.23 | max 0.4 | 1.1–1.4 | max 0.025 | max. 0.035 | 0.0008–0.005 |

| The main mechanical properties |
|-------------------------------|
| Yield Rp0.2 (MPa) | Tensile Rm (MPa) | Elongation A (%) | Reduction in cross section on fracture Z (%) | Brinell hardness (HBW) |
|------------------|-----------------|-----------------|-------------------------------------------|------------------------|
| 700 (≥)          | 900–1050        | 14              | 55                                        | 255–270                |
effect of Phosphorus and sulfur is almost negligible, and the Silicon content is normally so low in order to obtain the desired mechanical strength.[1–5], [9–20] The synergistic effect of Boron with other elements can enhance the Boron effect.[19] The effect of Boron on hardenability also depends on the amount of carbon in the steel. The effect of Boron increases in inverse proportion to the percentage of carbon present. Boron may also become ineffective if its state is changed by incorrect heat treatment. It should also be noted that the properties of quality carbon steel can be influenced by the presence of gases, especially Oxygen, Nitrogen and Hydrogen, as well as their reaction products.[1–5] These secondary elements penetrate into the steel usually from the scrap iron used, from the deoxidants or from the furnace environment.[1–5] The gas content depends largely on the method used for melting, deoxidation and casting, so that the final properties largely depend on the method used to elaborate them. Since Boron has a strong affinity for oxygen and nitrogen, these elements either must be removed or controlled for Boron to have its full hardenability effect. Accordingly, it has been the general practice to add Boron to steel with titanium and zirconium present to protect the Boron from nitrogen, and aluminum to protect Boron from oxygen. In addition to effecting deoxidation and providing protection of Boron from oxygen, aluminum is an effective grain refiner in production of ingot cast fine–grained steel.

For steel grades OLC15q, OLC35q and OLC45q, the international standards have provided the chemical composition and the qualitative characteristics that can be found in Tables 2–4.[22]

**Table 2.** The chemical composition [%] and the main mechanical properties of the high quality structural carbon steel, grade OLC15q [22]

| The chemical composition [%] |
|-----------------------------|
| C | Si | Mn | P | S | Cr | Ni | Al |
| 0.12–0.18 | 0.17–0.37 | 0.35–0.65 | 0.045 | 0.045 | max. 0.30 | 0.3 | 0.02 |

| The main mechanical properties |
|-------------------------------|
| Yield Rp0.2 (MPa) | Tensile Rm (MPa) | Elongation A (%) | Reduction in cross section on fracture Z (%) | Brinell hardness (HBW) |
| 541 (≥) | 982 (≥) | 33 | 13 | 113 |

**Table 3.** The chemical composition [%] and the main mechanical properties of the high quality structural carbon steel, grade OLC35q [22]

| The chemical composition [%] |
|-----------------------------|
| C | Si | Mn | P | S | Cr | Ni | Cu |
| 0.32–0.39 | 0.17–0.37 | 0.50–0.80 | 0.04 | 0.04 | max. 0.30 | 0.30 | 0.3 |

| The main mechanical properties |
|-------------------------------|
| Yield Rp0.2 (MPa) | Tensile Rm (MPa) | Elongation A (%) | Reduction in cross section on fracture Z (%) | Brinell hardness (HBW) |
| 873 (≥) | 551 (≥) | 34 | 22 | 134 |

**Table 4.** The chemical composition [%] and the main mechanical properties of the high quality structural carbon steel, grade OLC45q [22]

| The chemical composition [%] |
|-----------------------------|
| C | Si | Mn | P | S | Cr | Ni | Cu |
| 0.42–0.50 | 0.17–0.37 | 0.50–0.80 | 0.04 | 0.04 | max 0.30 | 0.3 | 0.3 |

| The main mechanical properties |
|-------------------------------|
| Yield Rp0.2 (MPa) | Tensile Rm (MPa) | Elongation A (%) | Reduction in cross section on fracture Z (%) | Brinell hardness (HBW) |
| 528 (≥) | 414 (≥) | 11 | 32 | 321 |
3. Research on Boron alloy steel 26MnB5

In 2010, a local steel company has produced the first Boron alloy steel 26MnB5 for the automobile industry, and soon this special mark of steel was also available for producers of machinery and equipment. In the meantime, were put up a few new brands of stainless steel with Boron, which are still in the process of being studied from the point of view of the practical utility: 27MnCrB5 and 33MnCrB5.

During the production of the 20MnB5q steel, there have appeared qualitative problems related to the realization of the calibre, the austenitic grain size, the microscopic purity, as well as the observance of the chemical composition and especially of the Carbon content occurred. The degree of chemical homogeneity in the 100–tones electric arc furnaces was scattered for segregating elements (especially Sulphur and Carbon), and Aluminum could not be dosed so as to be evenly distributed in the liquid steel. In order to avoid these qualitative deficiencies that have still been occurring in separate batches, it is important not to reduce the use of these high–grade steel, or to reduce the analysis gaps in the steelworks laboratories, to control the surfaces by the discharge test, or with non-destructive control equipment.

The most existing companies as well as the newest assemblies work only through the cold deformation process with the application of high reduction rates. In order to achieve these deformations in good conditions, without the appearance of cracks or other defects, the manufacturing conditions of round laminates without surface defects must be ensured. Therefore, it is necessary to observe strictly the technology of design, casting and lamination, in order to avoid surface defects in time. From the practice of manufacturing these grades of micro–alloyed Boron steels, it has been found that in many cases the defects of rolling in the finishing stands are defective with high weight in the case of lamination of ø12mm profile. The manufacturing and control technology flow applied here provides very severe interfacial receptions to the finishing rolling mill with a sample on the bend, which leads to very good results from the quality point of view. For steel grades OLC35q and OLC45q there are frequent cases when it is not ensured an advanced globulating annealing in order to ensure cold deformation without the risk of cracks occurring. In the bolt factories there are executed in intermediate sections by which the material is emblazoned and introduced into this state in the manufacturing process of the assembly elements.

Following the sampling of the 20MnB5q grade steel with the chemical composition shown in Table 5, the batch characteristics shown in Table 6 were obtained.[21] The quenching was carried out in two mediums: water and oil. The French requirements for the same 20MnB5q grade steel provide the following features presented in Table 7 and Table 8.[23] Comparing our data with that obtained on the French steel samples, it is not consistent with the Re and Rm values. However, French indications do not prescribe the technological additions to be used.[23]

Table 5. Chemical composition [%] of the structural carbon steel with Boron, grade 20MnB5q, according to the Romanian requirements [21]

| The chemical composition [%] |
|-----------------------------|
| C  | Mn | Si | S  | P  | Cu | Ni | Cr | B  | Al | As | Sn |
| 0.20 | 1.7 | 0.25 | 0.02 | 0.023 | 0.07 | 0.08 | 1.15 | 0.0035 | 0.007 | 0.011 | 0.012 |

Table 6. The heat–treatment environment and temperature, and the main mechanical properties of the structural carbon steel with Boron, grade 20MnB5q, according to the Romanian requirements [21]

| Quenching environment and temperature, [°C] | Tempering temperature, [°C] | Mechanical properties |
|--------------------------------------------|-------------------------------|----------------------|
|                                            |                               | Re [N/mm²] | Rm [N/mm²] | A [%] | Z [%] |
| Oil (900°C)                                | 500                           | 660       | 780       | 64    |      |
|                                            |                               | 640       | 760       | 17    | 64   |
|                                            |                               | 640       | 760       | 61    |      |
Table 7. Chemical composition [%] of the structural carbon steel with Boron, grade 20MnB5q, according to the French requirements [23]

|         | The chemical composition [%] |
|---------|-------------------------------|
|         | C    | Mn  | Si   | S    | P    | B    |
|         | 0.16–0.22 | 1.10–1.40 | 0.1–0.4 | max.0.035 | max.0.035 | 0.0008–0.005 |

Table 8. Main mechanical properties of the structural carbon steel with Boron, grade 20MnB5q, according to the French requirements [23]

| Quenching environment and temperature, °C | Tempering temperature, °C | Mechanical properties |
|------------------------------------------|---------------------------|-----------------------|
| Oil (900°C)                              | 500°C                     | Re [N/mm²]            |
|                                          |                            | Rm [N/mm²]            |
|                                          |                            | A [%]                 |
|                                          | min. 685                  | min. 830–1030         | min.11 |

The tests on a piece of steel bar imported from Finland, grade 20MnB5q, led to the following results on chemical composition (Table 9). [24] In order to determine the feasibility of the imported product, heating was performed at 860°C followed by quenching in water. The resulting values are shown in Table 10. From these data it is observed that the hardness values after hardening are higher than those obtained on the native steel.

Table 9. Chemical composition [%] of the structural carbon steel with Boron, grade 20MnB5q, according to the Finnish requirements [24]

|         | The chemical composition [%] |
|---------|-------------------------------|
|         | C    | Mn  | Si   | S    | P    | Cu  | Ni  | Cr  | B    | Ti   | V    |
|         | 0.22 | 1.22 | 0.21 | 0.029 | 0.023 | 0.27 | 0.22 | 0.31 | 0.005 | 0.03  | 0.04 |

Table 10. The hardness values after hardening

| Hardness measuring zones | Dimensions Φ mm | Hardness HRC (according colon 1) |
|--------------------------|-----------------|---------------------------------|
| ..........................| 22.5            | 43                              |
| ..........................| 15.0            | 45                              |
| ..........................| 12.0            | 45                              |
| ..........................| 9.5             | 45                              |
| ..........................| 8.0             | 47                              |
| ..........................| 6.0             | 47                              |

4. Results & Discussions
By making microstructures both for indigenous steel processed here, and for the foreign source in the state of delivery, it was found that the import steel has a slightly modified ferrite–perlite structure by an incomplete annealing treatment with tendencies of austenite formation in the globular state (Figure 1).
It was also found that austenitic grains are higher for imported steel than for indigenous steel, but in both cases they exhibit inhomogeneities with scores ranging from 1 to 5, a phenomenon evidenced by the microstructures of Figure 2.

The specialty literature suggests that it is very difficult to control the austenitic granulation in the case of Boron–micro–alloyed steels. After the 900°C water hardening of the indigenous steel rolled bars, martensitic structures of the shape of Figure 3 were obtained.
Analysing the microstructures of Figure 3 it is observed that the resulting martensite is rough and comes from a high-grain steel. After normalization at 860°C, a normalized state of ferrite-perlite structure is obtained, which tends to globulate cementite (Figure 4), but the martensitic structure resulting from the quenching of the normalized samples is still rough (Figure 5).

![Figure 4. Microstructure of normalized indigenous steel (500x)](image)

![Figure 5. Microstructure of normalized indigenous steel after water quenching (500x)](image)

Research on Finnish origin steel 20MnB5q revealed that after the quenching of the samples (with the dimensions Φ20.5; Φ12 and Φ6) there were very small structural differences, but compared to the indigenous steel of the same brand, it may be observed a higher degree of fineness of the structure (Figure 6). This is certified by the presence of technological additions of Vanadium and Titanium, which, besides the finishing effect of the structure, also contribute to the increase of the mechanical characteristics. For this reason, there was a difference between the resistance characteristics (Re and Rm) for indigenous steel as compared to the imported one – because, as it has been shown, the indigenous grade 20MnB5q steel produced in the first assimilation phases did not contain Vanadium and Titanium.

![Figure 6. Microstructure of Finnish origin steel, after water quenching (500x):](image)

(a) Φ20.5 mm samples; (b) Φ12 mm samples; (c) Φ6 mm samples

The analysis reveals an instability of the chemical composition for the 20MnB5q indigenous steel produced in the 100–tones basic electric furnace, resulting in the obligation to develop it in the 50–tones electric furnace, where the chemical composition is possible in a much narrower range.

4. Concluding remarks
The paper examines whether the studied steel can be cold–plastic processed without being globulised, but only cooled down stream, followed by a normalization treatment to obtain a finer structure with
globular tendencies. It should be noted that for this low–carbon and low–carbon micro–alloyed steel this possibility exists, but the extent to which deformation degree can be used in the neglected condition must be established.

Research on low–carbon and low–carbon micro–alloyed steel made technological improvements in manufacturing, which consisted of:

— production of this type of steel in electric furnaces with limitation of Carbon and Manganese content to the maximum admissible limit;
— use of Ferro–Titanium and Ferro–Vanadium admixtures for the chemical analysis of steel 0.02–0.04 Titanium and 0.01–0.03 Vanadium;
— performing samples with a cooling in water or oil to establish a more appropriate cooling medium;
— performing in parallel steel samples: recoil, globulised – hardened, recovered and steel: rolled, tempered, rebound, to determine the weight of the globulisation influence.

Taking this into account, the research at both the Faculty of Engineering Hunedoara and the Hunedoara indigenous platform continues in order to improve the manufacturing technology of the 20MnB5q grade steel.

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