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PRELIMINARY STRUCTURES ASSESSMENT OF SOME TRIP STEELS

Automotive industry is constantly interested in building cars made of light and high strength parts in order to reduce the emission levels, the fuel consumption and minimize the effects of a car crash. Some parts may be made of lighter materials, but the steel ones must compensate the strength needed for the car body. Research is made for finding new materials showing high strength combined with high ductility. Among them, transformation – induced – plasticity steels are of great interest, efforts being made to improve their characteristics. A new composition of such a steel is presented, its features being compared with those of three other steels of the same class and category. Optical microscopy at different magnifications is performed, together with Vickers hardness test. Structural particularities are found for each tested steel, justified by their own chemical compositions. The new steel reveals important characteristics: besides the mainly bainitic structure, it has both larger ferritic areas and amounts of retained austenite, making him proper for further study.

Keywords: TRIP steel; optical microscopy; Vickers hardness; retained austenite; car body material

1. Introduction

In order to increase the performance and safety of vehicles, car manufacturers are considering the large-scale use of parts made of low specific weight but high mechanical strength materials.

The aim is to constantly reduce the cars weight with direct consequences of fuel economy and engines low emission levels. One of the ways to achieve this goal is by studying steels showing high-strength combined with high ductility, exhibiting also the phenomenon of shock hardening, in order to use them as elements of the vehicle body.

The main class of high-strength steels showing this feature is Advanced High-Strength Steels (AHSS) which are materials that can be submitted to several technological steps in order to reach some specific intervals of strength, ductility, toughness and fatigue resistance values. Their microstructure comprises phases resulting from controlled heating and cooling processes ensuring the value ranges of properties mentioned above. These steels are light and thus will be in accordance with the safety regulations, emissions reduction and high performances at lower costs.

It should be noted that for these high strength steels the increase of strength parameters is much more important than the decrease of the ductility parameters [1]. This is particularly true for the group of steels named Conventional Advanced High-Strength Steels (AHSS) steels. Dual Phase steels (DP), Complex Phase steels (CP), Martensitic Complex Phase steels (MART/CP) and TRIP steels ("Transformation – induced plasticity" which implies a phase transformation in the material, when a stress is applied) belong to this group that is used in car body production [2].

The peculiarity of the last mentioned category of steels is that both strength and ductility can be improved by using the TRIP effect. However, their most important feature is the toughness increase by transforming the retained austenite when a shock occurs. Therefore, by means of chemical composition and manufacturing technology, the aim is to obtain a structure with retained austenite in optimal quantity [3,4].

TRIP steels have a volume fraction of retained austenite in their structure following an incomplete bainitic transformation. This is, in most steels, an undesirable constituent, leading to structure fragility and causing dimensional instability over time. Austenite can turn in a controlled way into martensite, leading to an increase in hardness.

Plastic deformation has a favorable influence on the austenite – to – martensite transformation, the deformation effort lead-

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ing to the martensitic transformation beginning at a temperature 30÷50 degrees higher than Ms value.

Considering TRIP steels, some amount of retained austenite is requested [5]. Another way to obtain this phase in the structure is the bainitic transformation, achieved by mixed mechanism. At the top of the ferrite plate, supersaturated in carbon and sometimes alloyed, there is an accumulation of carbon and alloying elements that locally change the chemical composition, lowering the transformation temperatures. This is actually the reason why the bainitic transformation is never complete, always keeping a small amount of untransformed (retained) austenite [6,7].

The operating mode of TRIP steel parts is based on this phenomenon. A small proportion of retained austenite is kept in the structure, maximum 10%. When a strong shock occurs, it will turn into martensite, instantly leading to a hardness increase of the steel part. Thus it diminishes the negative effects of the car body parts destruction.

Upon continuous cooling of the austenite into bainite, the latter has a significant tendency to retain a certain amount of austenite. The alloying elements have an important contribution to that effect. This particularity of the transformation, considered disadvantageous in the case of other materials, becomes the main reason for the production of TRIP steels.

The choice of the alloying elements and their concentrations will be done in order to obtain a controlled structure (ferrite, bainite and retained austenite in a proportion of maximum 15%). Their most important effects are summarized as follows:

Manganese. As an alloying element, with a concentration of over 1%, it has an significant effect of hardenability increase. It is an important gammageneous element, having some contribution to the stabilization of retained austenite. It also provides some increase in the cold deformability of steels.

Silicon dissolves in ferrite, stabilizing it and increasing its ductility, when present in a percentage of maximum 1.1-1.2%. Silicon has a strong influence on the elastic limit of steels, increasing it. When found in a proportion of over 1.3%, it worsens the deformability.

Because silicon does not form carbides, its existence in TRIP steel is essential for inhibiting cementite precipitation. As a consequence, it allows the austenite to be stabilized by carbon and thus the austenite will be richer in carbon and more stable [8]. Silicon decreases Ms because it activates the diffusion of carbon to austenite during the cooling [9,10].

Aluminum, in a quantity of max 1-1.5% does not affect the deformability of steels. Aluminum has a lower influence than silicon when it comes to delay the formation of cementite at the same concentration. Some substitution of silicon with aluminum was also studied [11].

TRIP steel containing 1.00 wt% Al shows the highest quantity of retained austenite and the greatest elongation. The carbon content of retained austenite is directly related with the aluminum content. Thus, aluminum stabilizes the carbon in the retained austenite [12].

Aluminum also leads to phase transformation in steels but its TRIP effect is less important than that of silicon [13].

Several other TRIP steels chemical compositions were studied in order to obtain better overall characteristics, such as a better control of the retained austenite fraction and its mechanical stability during tensile deformation, to improve the yield strength [14]. The differences in such steels mechanical properties correlated with the morphology, stability and content of retained austenite were also investigated [15].

This article aims to obtain and characterize a new TRIP steel composition, by comparison with 3 other existing steels of the same category and class.

2. Materials and Methods

Four TRIP alloys were produced, three of them having already studied chemical compositions [16-18] and the fourth TRIP steel had a new composition. All of them are shown in TABLE 1.

The composition of TRIP 4 steel was chosen considering the influence of each alloying element, Mn – gammageneous element, Si and Al – alphageneous elements. The addition of the chosen alloying elements (Mn, Si, Al) aims to ensure the formation of a large amount of retained austenite in order to give the steel the TRIP characteristic (transformation – induced plasticity).

2.1. Production

The experimental alloys were obtained in an induction furnace type Five CELES (ALU 600), in vacuum. The melt was protected along the casting by an argon atmosphere. The raw

TABLE 1

TRIP steels chemical compositions (Fe – balance)

Steel		C (%)	Mn (%)	Si (%)	S (%)	P (%)	Cu (%)	Al (%)	B (%)	Mo (%)	Cr (%)	Ni (%)	Ti (%)
TRIP 1	Ref. 7	0,2	1,6	0,3	N/A	N/A	N/A	1,8	N/A	N/A	N/A	N/A	N/A
	Cast	0,199	1,58	0,281	0,035	0,023	0,020	1,77	0,003	0,002	0,016	0,024	0,014
TRIP 2	Ref. 8	0,25	1,8	0,3	N/A	0.021	N/A	1,3	N/A	N/A	N/A	N/A	N/A
	Cast	0,251	1,81	0,307	0,029	0,024	0,033	1,29	0,003	0,005	0,028	0,030	0,080
TRIP 3	Ref. 9	0,1	5.18	0,2	0.008	0.015	0.03	0.026	N/A-	0.02	0.04	0.03	N/A
	Cast	0,105	5,20	0,213	0,007	0,019	0,016	0,002	0,002	0,001	0,012	0,020	0,008
TRIP 4	Chosen	0,1	6,1	0,3				0,6					
	Cast	**0,097**	**6,11**	**0,324**	**0,028**	**0,022**	**0,016**	**0,616**	**0,002**	**0,001**	**0,012**	**0,018**	**0,009**

materials used in the alloys production were preheated at 300°C in order to eliminate the moisture. The furnace prevents possible contamination and oxidation of the melt and also ensures a homogeneous structure and chemical composition of the casting.

2.1. Hot rolling and normalizing of the experimental TRIP steels samples

In order to obtain a structure proving a high homogeneity, internal stresses-free and exhibiting constituents ensuring the required mechanical characteristics, the test samples were submitted to hot rolling and normalizing.

Prior to hot rolling, all samples were heated to 1150°C/10 min in an oxidizing atmosphere. The rolling speed was 4 m/min. The TRIP steels samples were subjected to a number of 8 successive passes through the rolling mill, the thickness of the strip-type samples being reduced as a whole from 18 to 5 mm. Subsequently, it was decided to apply a normalizing heat treatment, the technological parameters being: T = 925°C/ holding time 0.5 h/ air cooling. The normalizing aimed to eliminate the banded structure as much as possible.

2.3. Structural investigation by optical microscopy

The preparation of the 4 metallographic samples was performed on a complete Struers preparation line (cutting, embedding, grinding). The reagent was Nital 2%, and the examination was performed on an Olympus BX51M metallographic microscope, equipped with the possibility of investigations in light or dark field and a magnification range of up to 1000×.

2.4. Hardness tests

The hardness tests were performed on an Innovatest Falcon 500 hardness tester, with a load varying between 10^{-3} kgf and 31 kgf and the possibility of performing Vickers, Brinell and Knoop hardness. All samples of the studied steels, both cast and hot rolled and normalized were tested at Vickers hardness with a 5 kgf load.

3. Results and Discussion

3.1. Optical microscopy structural investigations

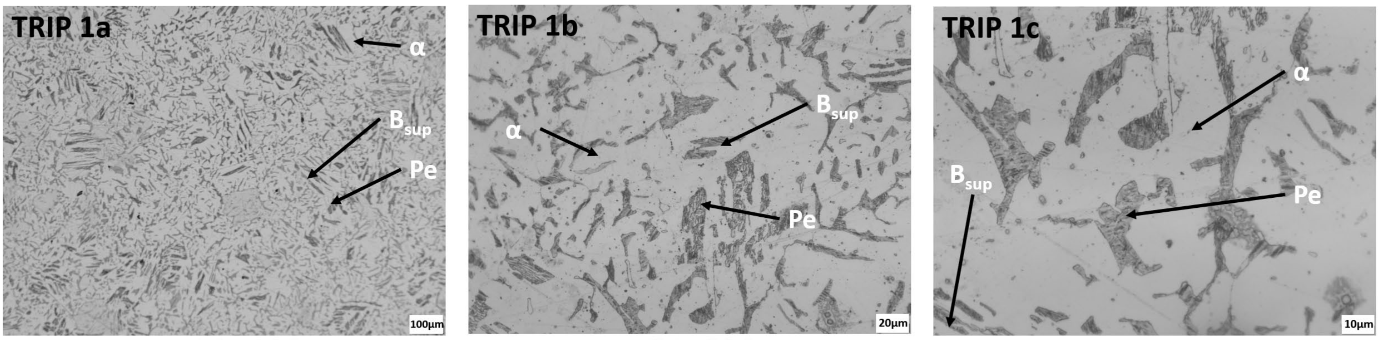
3.1.1. Metallographic analysis by optical microscopy after casting of the four TRIP steels

The purpose of these investigations was to observe the structure obtained after casting, with all the effects induced by the specificity of the transformations that take place during the production in the vacuum induction furnace with argon atmosphere and followed by controlled cooling.

The studies were performed at small magnifications of 100× to provide an overview of the microstructure, but also at a larger magnification of 500× to study certain structural details that were of interest. For the microstructural areas that exhibited a special appearance, the examinations were made at maximum magnifications of 1000×. All micrographs exhibit indications concerning the identified phases: α – ferrite, Pe – pearlite, B_{sup} – upper bainite, B_{inf} – lower bainite, α_{traces} – traces of ferrite, γ_{ret} – retained austenite (Fig. 1).

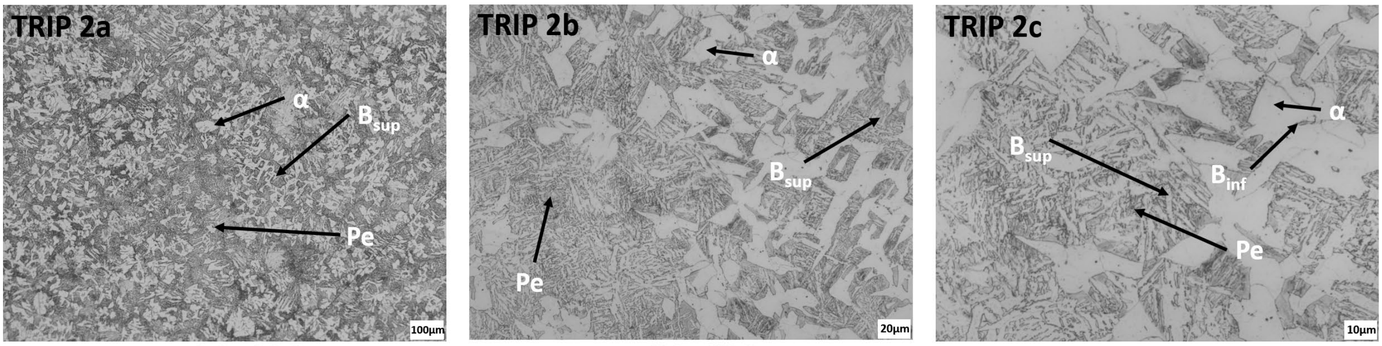
The overview of the TRIP 1 sample at 100× shows a structure with a slight overheating character in which mostly ferritic (light areas), pearlitic (dark areas) and bainitic (upper bainite, areas with rod-like distribution) formations are observed. The average hardness value of 117 HV5 confirms this structural aspect. The Widmannstätten character of the structure can be more easily traced in the investigated image at 500× and confirmed at 1000× (Fig. 2).

The microstructure of the TRIP 2 sample is characterized by a more significant decrease in ferritic areas in favor of pearlitic ones, the main cause being the slightly increased amount of carbon. Moreover, the average hardness value is consistent with this aspect, reaching 225 HV5. Along with ferrite and perlite, bainitic formations also appear in the structure. These are more visible in the micrograph recorded at 500×, where one can notice a rod-like morphology (upper bainite), along with a more acicular morphology (lower bainite). A structural detail of interest is observed in the micrograph recorded at 1000×, namely the pearlitic areas are crossed by light needle – like formations in which the Widmanstätten ferrite is identified. This ferrite locally exhibits a rod-like distribution, prior to the bainite formation.



(a) *100x* (b) *500x* (c) *1000x*

Fig. 1. Optical microscopy micrographs of the TRIP 1 sample, Nital 2%, different magnifications



(a) *100x* **(b)** *500x* **(c)** *1000x*

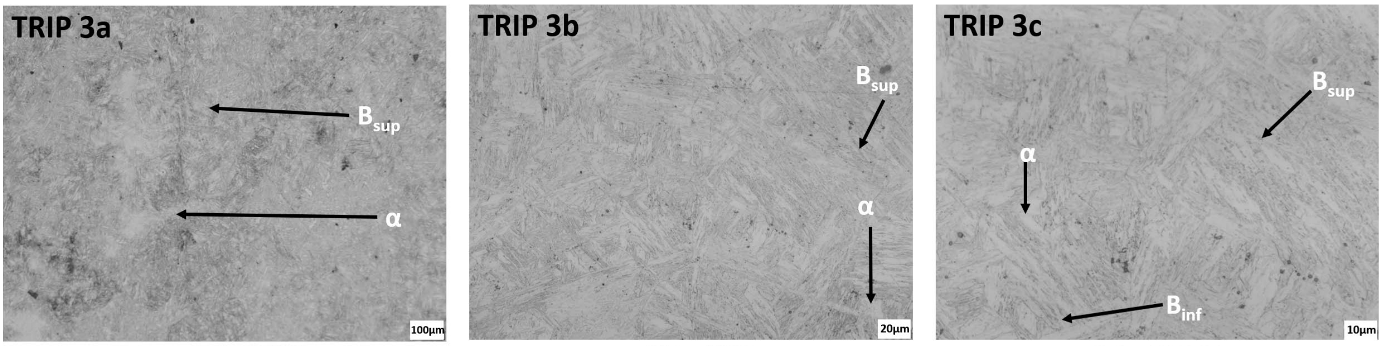
Fig. 2. Optical microscopy micrographs of the TRIP 2 sample, Nital 2%, different magnifications

The affiliation between Widmanstätten ferrite and the ferrite with a slight degree of carbon supersaturation, which initiates the bainitic transformation, suggestive of "massive transformation", is noted on this occasion (Fig. 3).

The increased hardenability determined by the Mn presence (of approx. 5.2%), as well as the susceptibility to overheating caused by Mn are the main initial data that allow the analysis of these structures. Thus, at low magnification, a mostly bainitic structure is noticed, with light traces (like a discontinuous network) of ferrite. In the process of solid state transformations evolving during cooling, the ferrite appears at the austenite grains limits which will later transform by an intermediate mechanism into bainite.

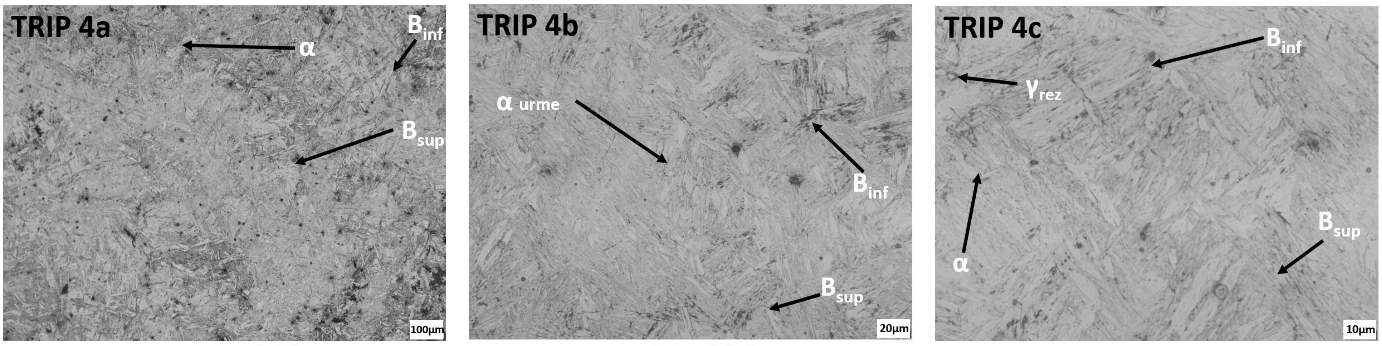
Although in small quantities, ferrite can provide indirect information about the austenite grain size. It was coarse (ASTM standard grain size 2-3), consequently it will induce fragility. The average recorded hardness of 361 HV5 is slightly higher than the usual bainite hardness, suggesting the fragile character of the structure. At higher magnification powers (500×) the bainite has the appearance of upper bainite, with an average length of the unit plate of 40÷60 µm, which confirms the coarse character of the structure. The maximum magnifying power brings as a novelty the existence of lower bainite typical structures (Fig. 4).

Overall, the structure of the TRIP 4 sample is quite similar to that of the TRIP 3 sample. The same overheating trend associated with the hardenability increase is also determined by the



(a) *100x* **(b)** *500x* **(c)** *1000x*

Fig. 3. Optical microscopy micrographs of the TRIP 3 sample, Nital 2%, different magnifications



(a) *100x* **(b)** *500x* **(c)** *1000x*

Fig. 4. Optical microscopy micrographs of the TRIP 4 sample, Nital 2%, different magnifications

presence of Mn in the structure. The average hardness value of 366 HV5 is close to that of the TRIP 3 sample. At higher magnifications (500×), along with the upper and lower bainite, one can see bright regions of ferrite in a larger amount. This latter is due to the presence of Al (0.6%), alphageneous element, in the structure.

Studies at maximum magnification powers (1000×) highlighted another structural detail, represented by the existence of polyhedral, bright micro-regions, which are ascribed to retained austenite. The existence of these formations is also related to the presence of a significant amount of Mn, known as a factor that favours the presence of retained austenite in the structure.

3.1.2. Metallographic analysis by optical microscopy after hot rolling and normalizing of the four TRIP steels

In order to have common features with the cast structures, investigations were made at the same magnifying powers (100×, 500×, 1000×) (Fig. 5).

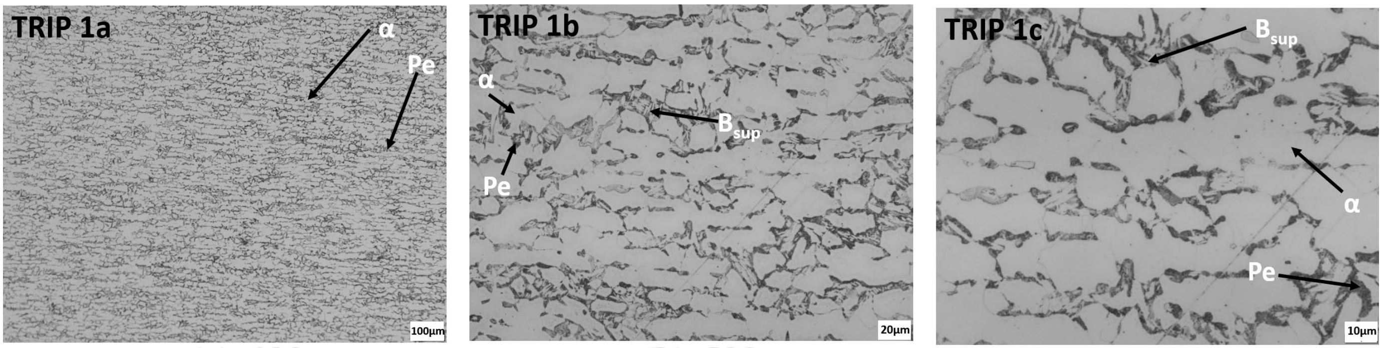
A regenerated structure can be seen in all images, the Widmanstätten character disappears, constituents have the same nature as these of the cast structure (ferrite, upper bainite, very small amounts of pearlite), all with a finer distribution as against the cast ones. The decrease in fragility is also revealed by the hardness test, which records an average value of 160 HV5, as compared to 172 HV5 recorded after making and casting (Fig. 6).

For the TRIP 2 sample also, the normalizing heat treatment regenerated the structure. Although the constituents are the same as in the cast structure, the general aspect highlights their finer distribution. The average hardness value (208 HV5), lower than the cast structure hardness (225 HV5) proves the fragility decrease (Fig. 7).

The general appearance of a fine, well organized structure, is observed in the normalized TRIP 3 sample. The constituents that make up the structure, finer compared to the cast structure, show little changes. At higher magnifications (500× or 1000×) along with the upper bainite, isolated areas of lower bainite also appear, confirming that Mn increases the alloy hardenability.

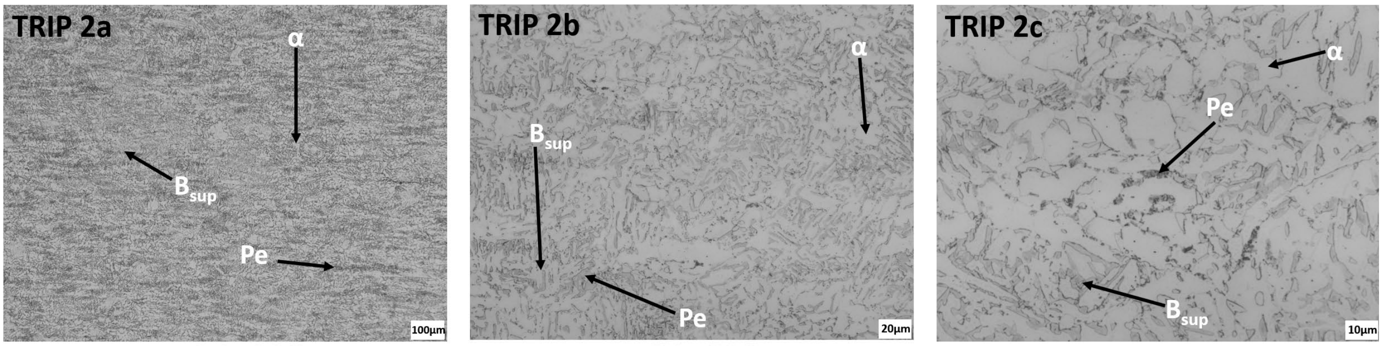
However, there is a restriction of the regions where the ferrite separates, although TRIP 3 steel has a lower amount of carbon (C ~ 0.1%) than the other steels previously analyzed (C ~ 0.2%). Certainly, it was also Mn that reduced the amount of proeutectoid ferrite, now found in the form of bainitic ferrite and a consequence of increased hardenability. Hardness tests (311 HV5) through higher values justify the predominantly bainitic structure. At the same time, lower hardness values are found when compared to the cast structure hardness. The fragility is once more attenuated (Fig. 8).

The analysis of the micrographs corresponding to the TRIP 4 sample concludes the series of structures to which normalizing was applied for the structure regeneration, after casting. The massive grain refinement is obvious in this case as well, without noticing important changes of the constituents as



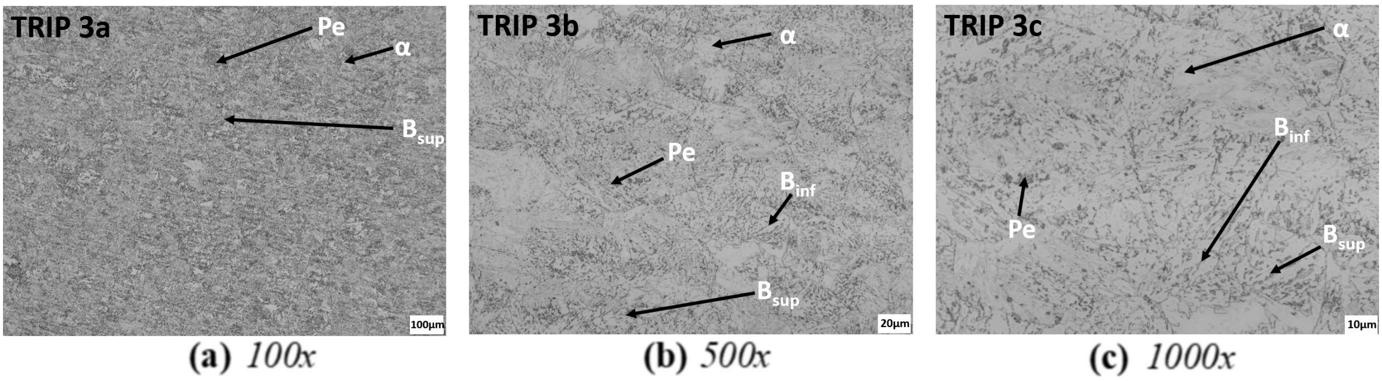
(a) *100x* (b) *500x* (c) *1000x*

Fig. 5. Optical microscopy micrographs of the hot rolled and normalized TRIP 1 sample, Nital 2%, different magnifications



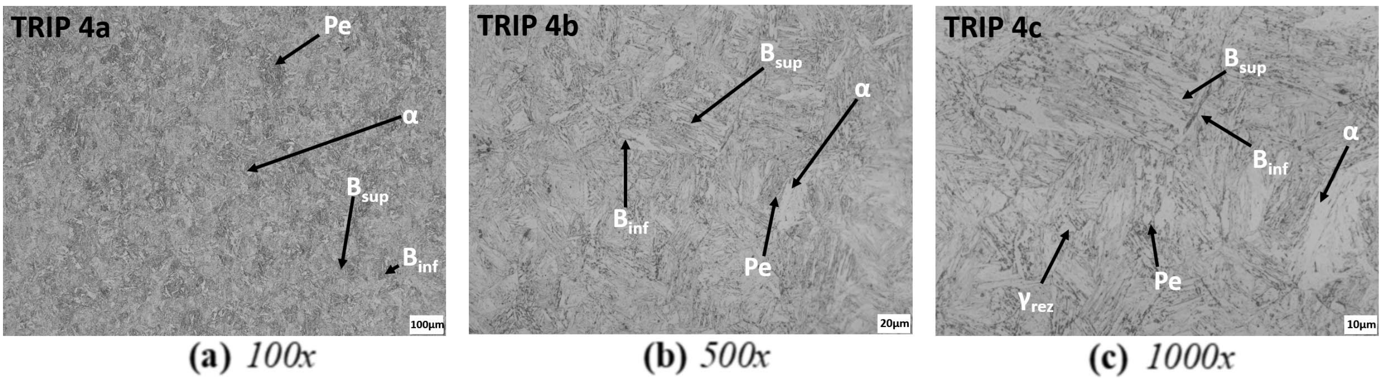
(a) *100x* (b) *500x* (c) *1000x*

Fig. 6. Optical microscopy micrographs of the hot rolled and normalized TRIP 2 sample, Nital 2%, different magnifications



(a) *100x* (b) *500x* (c) *1000x*

Fig. 7. Optical microscopy micrographs of the normalized TRIP 3 sample, Nital 2%, different magnifications



(a) *100x* (b) *500x* (c) *1000x*

Fig. 8. Optical microscopy micrographs of the normalized TRIP 4 sample, Nital 2%, different magnifications

compared to those identified after casting. However, their higher degree of fineness facilitates a clearer identification.

Thus, the structure is mainly bainitic (upper bainite and very small amounts of lower bainite), similar to that of the TRIP 3 sample, which allows to generalize the observation that Mn in large quantities increases the hardenability. Its gammageneous character could be highlighted at maximum magnifications (1000×) when, particularly for this sample, small regions with retained austenite could be observed.

Another structural detail observed also refers to the ferritic areas, slightly wider than in the TRIP 3 sample, similar in composition. These observations can be attributed to the presence in the chemical composition of an amount of 0.6% Al, alphageneous element.

Here, too, the hardness tests are in accordance with the structural features. Specifically, the measured average value of 345 HV5, lower than in the cast sample (366 HV5), confirms the decrease in fragility.

3.2. Hardness tests

3.2.1. Hardness tests of TRIP steels cast samples

The results of the hardness tests are presented in TABLE 2 where, together with the values for each test, the average hardness value after three measurements is shown.

TABLE 2

Hardness values of as-cast state TRIP steels

Alloy	Hardness (HV5)	Average Hardness (HV5)
TRIP 1	171	177
	181	
	180	
TRIP 2	220	225
	227	
	228	
TRIP 3	363	361
	361	
	358	
TRIP 4	363	366
	369	
	367	

One may see, correlating the hardness tests results with optical microscopy micrographs, that TRIP 3 and TRIP 4 steels have higher percentages of upper bainite in the structure, which leads to increased hardness but also to a possibility of obtaining higher amounts of retained austenite as a result of the applied heat treatments.

Following the summarization of the hardness test results after making of the steels, one may conclude that the TRIP 1 sample has the lowest hardness, with values between 171-181 HV5, followed by the TRIP 2 sample with values between 220-228 HV5, while the higher hardnesses are obtained in TRIP 3 and TRIP 4 samples with similar values, between 358-369 HV5.

The hardness values obtained for each and every sample are very close to each other, which confirms the cast structures homogeneity.

3.2.2. Hardness tests on hot rolled and normalized TRIP steels samples

The results are presented in TABLE 3 where, together with the values for each test, the average hardness value after three measurements is shown. These values are graphically represented in Fig. 9.

TABLE 3

TRIP steels hardness values after hot rolling and normalizing

Alloy	Hardness (HV5)	Average Hardness (HV5)
TRIP 1	160	160
	158	
	162	
TRIP 2	202	208
	209	
	214	
TRIP 3	310	311
	312	
	311	
TRIP 4	339	345
	348	
	348	

It can be seen that the alloys hardness decreases after normalizing due to the structural rearrangement of the crystalline grains, which leads to a ductility increase of the alloy. Apart from TRIP 3 steel where the hardness decreased by about 50 units, for the other steels the hardness decreased by about 20 units.

4. Conclusions

In all samples normalizing led to an important grain structure refinement which makes them suitable for further research.

In the case of TRIP 1 and TRIP 2 samples, similar in composition, there is no significant change in the constituents nature before and after regeneration annealing. This observation also remains valid for TRIP 3 and TRIP 4 samples, which also have similar chemical compositions. The only valid observation is the favourable influence of normalizing on the constituents fineness degree.

The hardness values of all samples, lower after normalizing when compared to those recorded after casting, confirms the fragility decrease by grain refinement.

However, structural peculiarities are found for each tested steel, justified by their own chemical compositions. The most important refer to the TRIP 4 sample which, besides the mainly bainitic structure, has both larger ferritic areas and amounts of retained austenite.

In the case of these studied TRIP steels, their structural characteristics obtained after hot rolling and normalizing make them suitable for further research aiming their application in the automotive industry.

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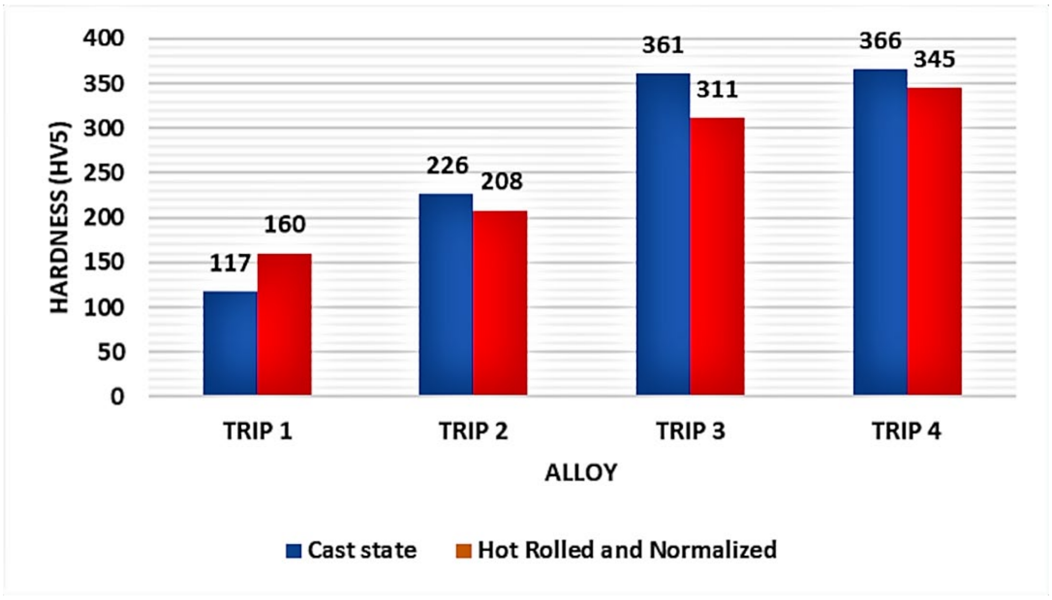

Fig. 9. Graphical representation of the TRIP steels hardness differences in cast and normalized states

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