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TRANSFORMATION INDUCED PLASTICITY STEELS USED IN AUTOMOTIVE INDUSTRY

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The work follows research done on 4 different TRIP steels that were elaborated in an induction furnace, under vacuum and controlled atmosphere. TRIP steels represent an important branch of materials in automotive industry due to their high shock absorption properties making them suitable to be used in the fabrication of protective parts that ensure the survival of passengers during an accident. The steels were analyzed from the point of view of microstructure and composition as well as from a hardness standpoint. The steel samples were also subjected to mechanical shocks, in order to simulate the received stress during a car-crash. After these tests the structure and hardness of the steels were analyzed. Studying the microstructure of the steels after casting, the sample that shows the presence of ferrite, bainite and retained austenite, had the best behavior during the crash-test, suggesting an optimum composition for application of the steel in automotive industry.

Keywords: TRIP steels, hardness, automotive, microstructure; SEM

1. Introduction

The continuous advancement of technology in various fields, from fuel combustion to mechanics, has led to a necessity for the development of more and more specialized materials [1, 2] for each of the parts used in the automotive industry. With the increase in power of the cars in traffic, safety is a top priority that needs to be addressed. Various steels have been used by automobile producers with different properties in terms of strength, ductility, elasticity, which cover the driver and passenger cabins to ensure their safety, such as AHSS steels, Dual Phase steels, TWIP Steels and TRIP steels.

TRIP steels show a complex set of formation mechanism and the optimization of the mechanical properties is difficult to obtain [3].

The transformation induced plasticity effect in these specific set of steels revolves around the transformation of retained austenite inside the structure into martensite during a moment of impact or transfer of energy throughout the steel

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which leads to a fast hardening of the material and lessening of the impact force. Good homogeneous distribution of the phases also has a strong impact on the hardening effect [3-5].

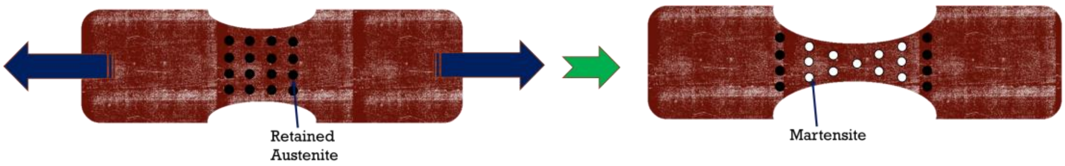

Fig. 1. TRIP effect in steels

In order to obtain the residual austenite certain heat treatments can be carried out to ensure a good content, usually involving intercritical annealing to create ferrite and austenite, followed by quenching and maintaining in the bainite formation temperature range to create superior bainite from which carbon is diffused into austenite and enriches it [6, 7]. The carbon enrichment of austenite has the purpose of ensuring that it remains stable during cooling and does not transform into martensite. Forming bainite also induces stresses in the material which possibly determine the formation of martensite.

Alloying elements also influence both the mechanical properties and the stabilization of the austenite in the structure. These have been studied by some authors [8, 9]. Silicon requires a minimum of 0.8 wt% concentration in order to block the formation of cementite and most TRIP steels show a 1.5 wt% in their composition [10, 11]. Aluminum helps in the formation of residual austenite and enhances the TRIP effect during mechanical testing of the steels [10]. Manganese is usually used as an alloying element in order to increase the toughness of the steel. Low alloyed TRIP steels have an approximate 1.5 wt% concentration of manganese [12, 13].

2. Experimental Procedure

Four different composition TRIP steels were developed and cast in an induction furnace with vacuum and controlled atmosphere (FIVES CELES, ALU 600, France) in order to observe the influence of various alloying elements such as Si, Mn and Al in the selected steel compositions. In order to ensure small impurity levels, high purity materials and alloys with known chemical composition were used as base materials for the development of the four TRIP steels. The compositions of these materials are shown in Table 1.

Table 1.

Chemical composition of base materials

Base Material	C	Mn	Si	S	P	Cu	Al	B	Pb	Mo	Cr	Ni	Nb	Ti	V	Fe
Alloy 1	0.182	1.51	0.343	0.019	0.019	0.031	0.897	0.002	0.00	0.001	0.025	0.024	0.033	0.048	0.004	96.9
Alloy 2	0.573	0.61	0.24	0.007	0.015	0.016	0.024	0.001	0	0	0.022	0.009	0.001	0.002	0	98.5
Alloy 3	0.053	0 .174	0 .093	0 .017	0 .012	0 .013	0 .039	0 .001	0	0	0 .002	0 .012	0 .006	0 .001	0 .000	9.6
Alloy 4	0.042	4.95	0.102	0.18	0.020	0.017	0.002	0.002	0.001	0.001	0.012	0.019	0.038	0.012	0.005	94.7
Mn	-	99.8	-	-	-	-	-	-	-	-	-	-	-	-	-	
Al	-	-	-	-	-	-	99.99	-	-	-	-	-	-	-	-	
Si	-	-	99.8	-	-	-	-	-	-	-	-	-	-	-	-	

The alloys and high purity materials were weighed and added in order to obtain calculated concentrations of C, Mn, Si and Al which are the elements of interest in the steels. They were combined in the induction furnace under vacuum and high temperature and afterwards cast into a copper mold to form ingots in Ar atmosphere. The induction furnace ensures that the samples have a homogeneous distribution of composition and the controlled atmosphere allows the casting of samples without surface oxidation. The cast materials can be observed in Fig. 2.

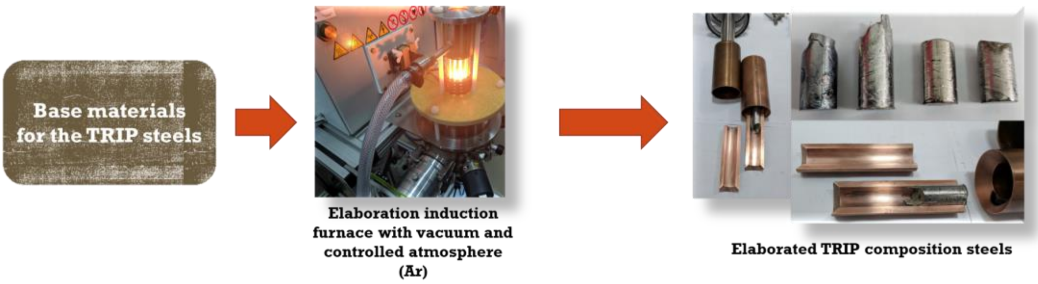

Fig. 2. Casting process of the chosen TRIP steels

After casting, the steels were hot rolled using a reversible roller, followed by a recrystallization annealing and cold rolling.

The hot rolling was done by pre-heating the samples at 1150°C in an electrical resistance furnace (Caloris 1206, Romania). The samples went through the roller 8 times, resulting in a decrease of thickness from 15 mm to 5 mm. The annealing was performed at a temperature of 900°C under vacuum in order to refine the granulation and reduce the stresses inside the alloys. The cold rolling further reduced the thickness of the cast material to 3.5 mm.

The alloys were also tested using a hardness testing equipment (INNOVATEST, Falcon 500, Netherlands) in order to observe the hardening effect of the Mn addition. The hardness was tested by using 5 kgf applied pressure and was measured on the Vickers scale.

In order to observe the microstructure by optical microscopy (OLYMPUS BX 51 M microscope), the surfaces were prepared using a Struers complete sample preparation line. The alloys were cut, mounted using heat activated resin, polished and subsequently attacked using NITAL 2%.

The composition of the first three steels follows the published works of Srivastava et. al., Kruijver et. al. and Merwin et. al. [14-16] in terms of C, Mn, Al and Si content. The fourth alloy is a new and not previously analyzed TRIP steel.

3. Results and discussion.

The chemical composition of the steels was analyzed by Optical Emission Spectrometry (LECO, GDS 500A 10x0.33µF, USA) after casting. The abundance in alloying elements can be observed in table 2.

Table 2.

Chemical composition of cast TRIP steels

Alloy	C	Mn	Si	S	P	Cu	Al	B	Pb	Mo	Cr	Ni	Nb	Ti	V	Fe
TRIP 1	0.2	1.6	0.3	0.018	0.023	0.02	1.77	0.003	0.016	0.002	0.016	0.024	0.048	0.014	0.006	96
TRIP 2	0.25	1.8	0.3	0.015	0.02	0.03	1.3	0.003	0.015	0.005	0.028	0.03	0.058	0.08	0.008	96
TRIP 3	0.1	5.2	0.2	0.017	0.019	0.016	0.002	0.002	0	0	0.012	0.02	0.033	0.008	0.003	94.4
TRIP 4	0.1	6.1	0.3	0.018	0.022	0.016	0.6	0.002	0.004	0.001	0.012	0.018	0.028	0.009	0.006	92.7

In order to determine chemical composition influence on the microstructure and mechanical properties, the four TRIP steels were subjected to microscopic analysis and hardness test, after casting and cold rolling, respectively.

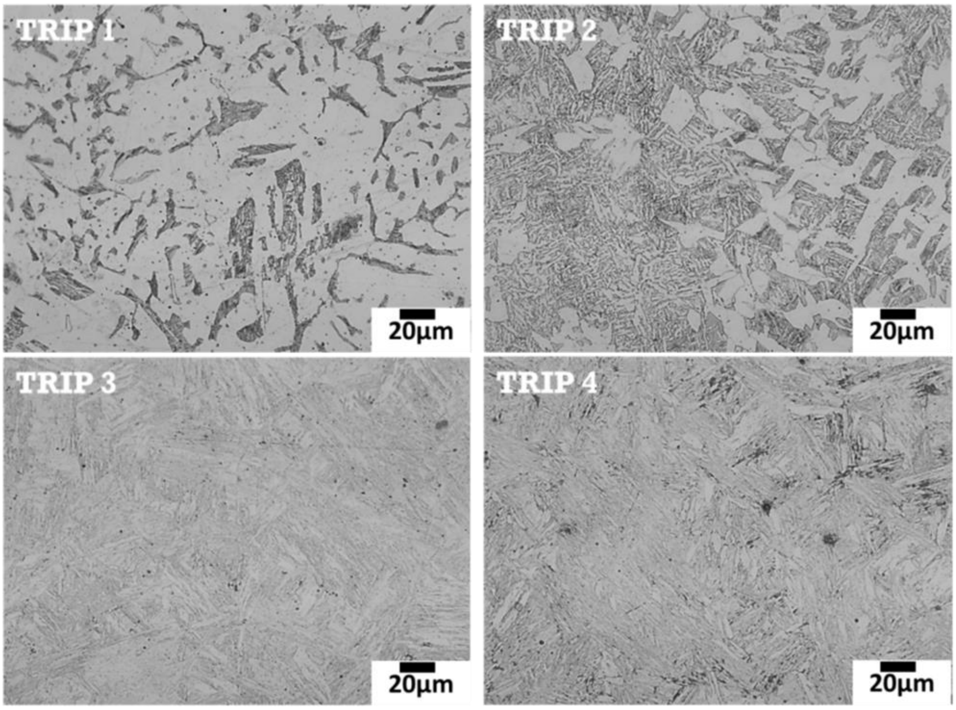

Fig. 3. Microstructure of TRIP steels after casting, NITAL 2% etched, 500x magnification.

Each of the 4 micrographs displays a unique structure, generated by the different chemical compositions of the developed TRIP steels. The one thing that they have in common is the generally coarse aspect of overheating given by the solidification after casting. In Fig. 3, the TRIP 1 steel shows the most obvious form of Widmannstaetten overheating, followed by separation of needle shaped ferrite. Ferrite remains the main phase of the steel, with both acicular and cellular distributions inside the alloy. The high amount of ferrite is due to the small C content (approximately 0.2%) and also because of the small concentration in alloying elements which puts TRIP 1 in the region of low-alloyed steels. The darker zones represent a combination of equilibrium phases (pearlite) and also non-equilibrium formed by intermediary mechanisms. They are represented by superior bainite which is displayed through a rod-like morphology. The TRIP 2 steel microstructure reveals a strong increase in the superior bainite proportion (compared to the TRIP 1 steel) as well as polyhedral ferrite islands and some pearlite. This is due to a superior hardenability compared to TRIP 1 steel, as a result of a higher C and Mn. The micrograph corresponding to TRIP 3 shows a predominantly bainitic structure although the C content is kept low. This is due to the presence of a high amount of Mn that increased the hardenability of the steel. The brighter areas are in a lower proportion and represent the ferrite phase. Small polyhedral areas with increased brightness are also observable that are attributed to the formation of retained austenite. The presence of this phase is the consequence of the massive bainitic transformation that has the characteristic of leaving a small amount of untransformed austenite which is considered "retained".

The TRIP 4 micrograph is similar to TRIP 3. It is composed primarily of bainite, alongside with islands of retained austenite and ferrite, but ferrite has a higher degree of dispersion and is found in a higher proportion. This can be attributed to the presence of Al which is an alpha-gen type element. The hardness of the cast materials is displayed in Table 3. The hardness is the mean value of 3 measurements.

Table 3.

Hardness of cast TRIP alloys

Alloy	Hardness
TRIP 1	117 HV
TRIP 2	225 HV
TRIP 3	361 HV
TRIP 4	366 HV

The influence of the Mn content is clearly visible in the hardness of the materials: as can be observed, the hardness increases with increasing Mn content. After hot rolling, annealing and cold rolling, the alloys were again prepared for metallographic analysis and the changes to the microstructure were observed in Fig. 4.

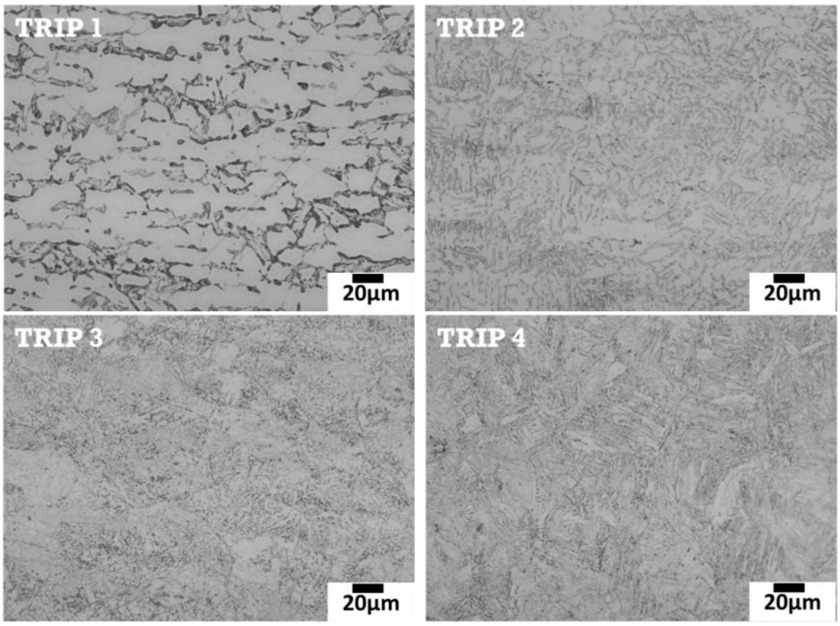

Fig. 4. Microstructure of TRIP steels after hot rolling, annealing and cold rolling, NITAL 2% etched, 500x magnification

The annealing heat treatment applied to the developed and plastic deformed TRIP steels had the main purpose of regenerating and homogenizing the structure, which was disrupted by the hot working process. Therefore, in Fig. 4, the regenerated structures can be observed in which the grain refinement is visible although the morphologies are different, again correlated with the chemical composition of each steel.

The microstructure corresponding to the regenerated TRIP 1 shows a refined structure, predominantly ferritic combined with the formation of bainite and pearlite at the grain boundary. The slight increase in hardness after annealing (table 4) is the result of the finer granulation that resulted from the process.

In the case of TRIP 2, it displays a structure of approximately 60-70% bainite. Ferrite, pearlite and small bright polyhedral areas of retained austenite are also present.

The TRIP 3 and TRIP 4 microstructures after annealing show the presence of bainite, ferrite and retained austenite. The difference is that in the TRIP 4, the proportion of ferrite is increased, and the retained austenite islands seem to present a more controlled distribution. This relative homogeneous distribution of small ferrite islands in bainite is probably the reason for the increased hardness of TRIP 4 compared with TRIP 3 (table 4).

Taking into account that these steels need to show a very different behavior: good formability, mechanical resistance, and excellent shock absorption capacities, from the analyzed micrographs, TRIP 4 offers the promise of being the most suitable alloy.

Table 4.

Hardness of TRIP steels after rolling and annealing.

Alloy	**Hardness**
TRIP 1	160 HV
TRIP 2	208 HV
TRIP 3	311 HV
TRIP 4	345 HV

4. Conclusions

Four different composition TRIP steels were developed and cast using an induction furnace with vacuum and controlled Ar atmosphere.

The steels with different chemical compositions were hot rolled, annealed and cold rolled in order to obtain a refined microstructure. The retained austenite which is needed to obtain the TRIP hardening effect during impact is observable in the TRIP steels in various proportions.

The TRIP 3 and TRIP 4 alloys display the highest hardness due to the Mn content. The TRIP 4 steel presents a more homogeneous structure and shows promise as a suitable alloy due to a more refined distribution of retained austenite in the structure and due to the Al content, that allows the ferrite to remain untransformed during the plastic deformation and heat-treatment.

R E F E R E N C E S

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