Novel Trip Steel – Characterization, Impact Test and Comparison with Existing Trip Steels

M C Pantilimon¹, C I Tarcea*, C S Gradinaru¹, G Coman¹, S Ciuca¹, M Sohaciu¹ and C Predescu¹
¹University Politehnica of Bucharest, Faculty of Material Science and Engineering, Splaiul Independentei nr. 313, RO-060042, Bucharest, Romania

*E-mail: tarceaclaudia@yahoo.com

Abstract. 4 TRIP steels were produced by use of an induction furnace with controlled atmosphere and vacuum, one of which having a completely new chemical composition with the purpose of obtaining an increased reaction during impact when compared to the other, already documented, steels. This study follows the heat treatment used in order to obtain the TRIP effect in the produced steels and the reaction that the steels exhibit when submitted to an impact test used to simulate a car crash at approximately 60 km/h. The preparation of the samples for both characterization and testing follow standard procedures in terms of analysis. The crash-like tests were performed by using an INSTRON 9340 Ceast which generated an impact energy of 18J. The comparison between the different types of TRIP steels helps to determine the best application of the purposed steel in the automotive industry.

1. Introduction

The selection of steel for critical safety applications follows two general guidelines. These guidelines are based on the principle that, in a sudden deceleration resulting from an accident, energy must be dissipated in a controlled manner so that the deceleration of the occupants does not exceed certain thresholds, maximizing survival and minimizing the chances of injury [1]. The amount of energy absorbed by the material is strongly influenced by the stress behavior of the material, which is controlled by the microstructure of the material [2]. The acronym TRIP for transformation-induced plasticity was originally invented by Zackay et al. [3] to classify all alloys with a unique combination of high strength and improved ductility imposed by the deformation-induced transformation of austenite into martensite. The phenomenological characteristics that distinguish martensitic transformations have been reviewed by Cahn et. al. [4]. Martensitic transformation is characterized by high transformation velocities in which atoms move at distances smaller than the atomic distance.

The microstructure of TRIP assisted steels is obtained by performing a heat treatment in two stages after cold rolling. The first stage of the heat treatment is performed at a slightly higher temperature in the bidirectional region $\alpha + \gamma$, leading to a microstructure of approximately 50% austenite and 50% ferrite. A cooling with isothermal holding time after partial austenitization is used to have a controlled structure formed initially in ferrite and austenite and finally the austenite will be transformed isothermally in upper bainite. During bainite formation, a little quantity of carbon respectively alloying elements retrodiffuse into the not transformed yet austenitic islands, [5] enriching them and modifying the critical points of transformation austenite-martensite (permutes to lower values the temperatures of MS and MF). According to the specific phenomena of bainitic transformation, the
respective areas remain in the form of retained austenite. Usually undesirable, this will represent micro-regions in which in case of shock, they will turn into martensite, increasing the mechanical resistance to impact.

Most published damage data refer to the reliability of a steel with its energy absorption during a dynamic test; Typically, the tests performed refer to traction [6-8] or column-compression tests [9].

The elaboration process of the studied TRIP steels was detailed in a previous study which included both obtaining and rolling processes. The purpose was to change the dimensions in order to perform impact tests on them [10].

Upgrading TRIP steels using new compositions is a necessity in the industry especially due to the fact that cars have increasing speed capabilities that can involve in the event of an accident and more damaging impact forces, and the protection and safety of the passengers must be a factor of interest and research.

2. Experimental Procedure and Discussions

The heat treatments used involved rapid heating to a bidirectional temperature $\alpha + \gamma$, leading to a microstructure of about 50% austenite and 50% ferrite with maintenance at this temperature, then rapid cooling in the bainite formation range, leading to a diffusion of carbon into austenitic islands to form residual austenite, followed by cooling in air. In order to obtain this thermal path, a bath of Barium Chloride ($\text{BaCl}_2$) salt was used. The principle of heat treatment involves heating the alloy to a temperature close to the critical upper $A_3$, followed by cooling close to the bainite formation temperature. These temperatures vary depending on the composition of the alloy and involve a mathematical calculation to determine the critical temperatures $A_1$ and $A_3$ using the formulas:

$$A_1 = 727 - 14[\%\text{Mn} + \%\text{Ni}] + 22[\%\text{Si} + \%\text{Cr} + \%\text{Al}]$$

$$A_3 = 855 - 180[\%\text{C}] - 14[\%\text{Mn}] - 18[\%\text{Ni}] = 45[\%\text{Si}] + 1.7[\%\text{Cr} + \%\text{Al}] + 45$$

Following the determination of the values $T_{A1}$ and $T_{A3}$, the temperature of the heat treatment to be applied to each steel can be calculated using the formula:

$$T_T = \frac{A_1 + A_3}{2}$$

Using these formulas depending on the composition of each TRIP alloy, it was possible to determine the temperature required to obtain the optimal amount of residual austenite for each steel produced.

| Table 1. Temperatures for $T_{A1}$, $T_{A3}$ and heat treatment ($T_T$) for processed steels. |
|---------------------------------------------------------------|
| Sample    | $T_{A1}$ ($°C$) | $T_{A3}$ ($°C$) | $T_T$ ($°C$) |
|-----------|----------------|----------------|-------------|
| TRIP 1    | 750            | 813            | 781.5       |
| TRIP 2    | 737            | 800            | 768.5       |
| TRIP 3    | 659            | 773            | 716         |
| TRIP 4    | 661            | 766            | 713.5       |

The compositional calculations led to the determination of a unique heat treatment regime for each alloy. These regimes can be seen in Figure 1.

As can be seen the same bainitic isothermal parameters were applied for all steels. A Nabertherm oven with a power of 13kW and a maximum operating temperature of 1600°C was used to heat the
samples at the $T_f$ heat treatment temperature, and the salt bath was heated in parallel in a Caloris sintering furnace at temperature of 400°C in order to facilitate the formation of lower bainite. This purpose was based on the reasoning that only lower bainite tends to retain in structure a small percentage of untransformed (retained) austenite.

The steels were then analyzed using Optical Microscopy. About 4 mm was cut from each steel. These were subsequently embedded in the resin and sanded to the level of metallic luster. For the purpose of metallographic analysis, the samples were attacked with 2% NITAL reagent to highlight the grains and structure, then they were examined using an Olympus type metallographic microscope (BX 51 M), equipped with the possibility of light or dark field investigations and a magnification field up to 1000x.

The hardness tests were performed on an Innovatest Falcon 500 microdurimeter, with an intelligent load application system, a load ranging between 1g and 31 kgf and the possibility of performing Vickers, Brinel and Knoop hardnesses. The steels were tested at a load of 5kgf and the results presented in table 2 are the average values of 3 measurements.

**Figure 1.** Heat treatment regimes applied to TRIP steels.

**Table 2.** Hardness values of TRIP steels after heat treatment.

| Sample | Hardness (HV) | Load (Kgf) |
|--------|---------------|------------|
| TRIP 1 | 221           | 5          |
| TRIP 2 | 200           | 5          |
| TRIP 3 | 341           | 5          |
| TRIP 4 | 316           | 5          |
Optical microscopy images can be seen in Figure 2.

![Optical microscopy images of TRIP steels after heat treatment](image)

**Figure 2.** Optical microscopy images of TRIP steels after heat treatment: (a)-100X; (b) 1000x.

In all cases the structure consists of ferrite and lower bainite. As the alloying degree increases, the hardenability of the steel increases too, leading to a higher amount of bainite. Small bright, insular areas accompany the bainitic regions. It’s easy to observe that the density and size of these areas increase with increasing of % Mn, known like an element that on the one hand increases the hardenability and on the other hand induces the tendency to retain untransformed austenite. In conclusion, the mentioned areas are clearly retained austenite. Saying this, the main objective of the purposed heat treatments is considered to be achieved. Regarding the proportion of ferrite, which intentionally exists in the structure, it is appreciated that it does not contribute to an important increase of the mechanical resistance. It should not be omitted the fact that the TRIP steel sheets, just like any
other sheet used in the manufacture of the car body must first of all be processed by specific deformation techniques, and an advanced machinability is primarily ensured by the ferrite.

It must to be underlined that the main purpose of TRIP steels is to provide protection to the passengers of a car in the event of an accident. One of the most dangerous impacts is the frontal one because the energy is concentrated on a smaller surface and the direction of impact is perpendicular to the position of the car occupants. Furthermore, the research will be directed to the testing in simulated impact conditions of the 4 heat treated steels, especially having the structure adapted to withstand the impact in an optimized manner. The test results will prove which steel had the most appropriate behavior.

Concretely, the impact test was designed with the idea of a frontal impact, at a speed of about 60km / h, and the samples were tested under the same conditions in order to observe the energy to which they are subjected at the time of impact. INSTRON Ceast 9340 equipment was used to perform the impact tests on the samples, which has a maximum impact energy of 405 J, a maximum force of 90kN, an impact speed of up to 4.65 m / s and the possibility to operate in an environment controlled by temperature between 50 and 100 ° C. Data is purchased electronically and displayed using VisualIMPACT V.6 and CeastVIEW software.

For testing the heat-treated samples had the surfaces cleaned of the salt film resulting from the isothermal holding period and then positioned on the impact support. The parameters used in the process are:

![Image showing comparison of forces](image)

**Figure 3.** Comparison of the forces with which each type of steel responds at the moment of impact.

In Figure 3, the equipment registered the reaction of each steel and the absorption of energy. What is clearly visible is that in the case of TRIP 4 it presence a higher and faster energy absorption than it’s counterparts which are already documented TRIP steel compositions that were reproduced for this experiment. Each of the reproduced steels was studied as follows: TRIP 1 by Krujiver et al., [11], TRIP 2 by Srivastava et al., [5] and TRIP 3 by Merwin [12].

After impact, TRIP steels have been tested for hardness changes, which should be visible when obtaining the desired transformations in the structure.
### Table 3. Hardness values of TRIP steels after impact.

| Sample | Hardness (HV) | Load (Kgf) |
|--------|---------------|------------|
| TRIP 1 | 228           | 5          |
| TRIP 2 | 240           | 5          |
| TRIP 3 | 348           | 5          |
| TRIP 4 | 349           | 5          |

In all steels we can observe by comparing the data from Table 2 and Table 3 that the hardness has increased after the impact tests. The result is dual: under impact inherently the ferrite was cold hardened determining a certain increase in hardness, but the stronger effect is concentrated on the retained austenite, which transforms into martensite. This transformation is stimulated by the plastic deformation which acts like a motrice force, inducing the mentioned phenomenon. This is one of the clear indications that the transformation induced plasticity effect has been developed in the steels via the heat-treatment applied and that it varies greatly based on the composition of the steel.

### 3. Conclusion and perspectives

Four steels from the TRIP category have been proposed for elaboration and research, their chemical composition has been specially adapted in order to obtain a controlled structure: the carbon content was relatively low in order to obtain a majority ferritic structure which admits a corresponding plastic deformation, the presence of some alloying elements able to inhibit the carbides formation and some alloying elements having the property to keep in structure a small amount of retained austenite.

A special structure according to the specific solicitations in automotive industry has imposed an unconventional heat treatment to be proposed in order to fix a required amount of ferrite and to obtain lower bainite always accompanied by a small quantity of retained austenite. Optical microscopy investigations justified the correctness of the applied heat treatment.

An impact stress test has simulated as eloquently as possible the shock in case of a road accident. The behavior of the investigated steels has proved to be appropriate. These aspects have been very well justified by the choice of the structure. The presence of a small amount of retained austenite in the structure, usually unwanted, has been shown to be beneficial. During the shock it has transformed into martensite increasing the mechanical resistance and diminishing the effects of the impact. This is one of the clear indications that the transformation induced plasticity effect has been developed in the steels.

### Acknowledgement

The work has been funded by the Operational Programme Human Capital of the Ministry of European Funds through the Financial Agreement 51668/09.07.2019, SMIS code 124705.

### 4. References

[1] Urbina P, Orta P and Ahuett-Garza H 2014 *International Journal of Automotive Technology* **15**(6) 909-17

[2] Rana R and Singh S B 2016 *Automotive Steels: Design, Metallurgy, Processing and Applications* Woodhead Publishing

[3] Zackay VF, Parker ER, Fahr D and Busch R 1967 *ASM Trans Quart* **60**(2) 252-9

[4] Cahn R and Haasen P 1983 *Elsevier Science Publishers* **3** 987-90.

[5] Srivastava A K, Jha G, Gope N and Singh S 2006 *Materials Characterization* **57**(2) 127-35

[6] Kang W, Cho S, Huh H and Chung D 1998 *SAE Technical Paper* 0148-7191

[7] Nakanishi E, Tateno H, Hishida Y and Shibata K 1998 *SAE Technical Paper* 0148-7191

[8] Bleck W and Schael I 2000 *Steel research* **71**(5) 173-8
[9] Mizui N, Fukui K, Kojima N, Yamamoto M, Kawaguchi Y, Okamoto A and Nakazawa Y 1997 SAE transactions 205-10
[10] Pantilimon M C, Berbecaru A, Ciuca S, Sohaciu M, Reumont G, Coman G and Predescu C 2019 UPB Sci Bull, Series B, 81(4)
[11] Kruijver S, Zhao L, Sietsma J, Offerman S, Van Dijk N, Lauridsen E Margulies L, Grigull S Poulsen H F and van der Zwaag S 2003 In situ observations on the mechanical stability of austenite in TRIP-steel. Journal de Physique IV (Proc.) EDP sciences
[12] Merwin M 2007 Low-carbon manganese TRIP steels. Materials science forum: Trans Tech Publ.