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Investigation of Microstructure and Mechanical Properties of Newly Developed Advanced High Strength TRIP Steel

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ABSTRACT

In this research, the heat treatment and production of high-strength advanced TRIP1100 steel were investigated and then the mechanical properties of the welds of this steel were evaluated by spot welding. For this purpose, the effect of rolling process and heat treatment of alloy steel sheets to achieve the ultra-high strength TRIP1100 steel microstructure was discussed. Microstructural examinations by Scanning Electron Microscopy (SEM) identified ferrite with bainite phases and martensite in matrix. The microstructural characteristics were examined using SEM microscopy with Electron Backscatter Diffraction (EBSD) analysis. The EBSD results showed that the type and orientation of the grains changed and the fraction of high-angle to low-angle boundaries in the present steel varied due to the presence of different phases. The EBSD results showed the acceptable rate of primary austenite in the structure according to the phaseology of this method. Having desirable mechanical properties was one of the most important results of this study, which at the same time maintained impact resistance and mechanical strength.

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1. INTRODUCTION

In recent years, advanced high-strength steels have been widely developed due to the need to increase the safety of car occupants and save fuel, and this is due to the ability to withstand static and dynamic forces, especially in accidents. This advantage of steels makes it possible to make parts with complex shapes and enhanced designs with forming processes. In recent years, advanced high strength steels have been evolving and their applications are developing especially in the automotive industry. These steels are now being used in vehicles to improve their efficiency and safety. TRIP steel are a class of high-strength steel alloys typically used in naval and marine applications and in the automotive industry. TRIP stands for "Transformation induced plasticity," which implies a phase transformation in the material, typically when a stress is applied. These alloys are known to possess an outstanding combination of strength and ductility [1]. Currently, TRIP (transformation plasticity) steels with low alloying elements are known so that the total amount of alloying elements in these steels does not reach more than 3.5%. In these steels, due to the application of thermomechanical processes, austenite to martensite transforms at room temperature. TRIP steels offer an extraordinary combination of strength and flexibility. As a result, it is suitable for making reinforced parts with complex shapes [2-5]. The microstructure of high-strength steels makes it possible to achieve greater elongation and a combination of excellent strength and flexibility for these steels. TRIP steels have a multi-phase microstructure with a complex shape, which includes a ferrite field with hard phases within it. This alloy contains varying amounts of residual austenite, ranging from 5 to 18% in some cases. Carbide-free bainite phases in soft ferrite field are present in this alloy. The austenite of

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these steels is transformed into martensite during plastic deformation. Therefore, today, the use of these steels in the automotive industry is a hot topic and is under research and development [6]. Applications of this steel in the upper pillar B include roof columns, engine support chassis, front and rear rails and seat frame [7] .The microstructure of TRIP steels consists of ferrite, bainite, martensite and greater than 5% of retained austenite. The latter is the most important phase constituent of TRIP steels, because its stress induced transformation to martensite results in work hardening of steel during deformation, and hence delays the onset of necking, eventually leading to a higher ductility [7, 8]. The bainite is formed by isothermal holding at a temperature below the bainite start transformation temperature (Bs) during cooling from intercritical annealing temperature.

TRIP steels have less volume fraction of hard phases such as martensite and bainite, therefore their initial yield stress is usually lower than that of DP steels. However, due to the progressive transformation of austenite to martensite, TRIP steels can reach ultimate tensile strength (UTS) values even higher than those for DP steels [9]. In this research, the process of production and manufacture of new TRIP1100 steel from a special alloy was investigated. The aim of this study was to achieve the best microstructural quality with suitable primary austenite and optimal mechanical properties.

2. MATERIALS AND METHODS

In this study, the test steel was cast by an induction furnace under the control of basic parameters, Materials that were melted and then cast. Among the wastes were steel sheets that had been calculated and carefully adjusted before chemical analysis. the chemical composition of this steels of which was analyzed by spectroscopy, is presented in Table 1. Cast ingots weighing 30 kg with dimensions of 100 × 100 × 30 cm after homogenization in the furnace for 1 hour at a temperature of 1000 ° C by hot rolling process and in 3 passes reached a thickness of 3.2 mm [8]. The heated rolling sheets were then cooled in an oven at 1000 ° C for 1 hour after annealing and then cooled rolling to a thickness of 1 mm in hydrochloric acid solution after mechanical deoxidation and acid washing. In order to achieve the desired microstructures (TRIP1100), the heat treatment cycle was designed using dilatometry at 950 ° C with sample dimensions in terms of 10 × 5 × 5 cm. By calculating from the dilatometry data, the intercritical temperatures and the starting temperature of the binetic and martensitic transformations were obtained, which are presented in Table 2 [9].

Figure 1 shows a schematic of the heat treatment cycle designed and performed on the test steel to achieve the desired structure. In order to achieve the microstructure of TRIP1100 steel, the sheets were subjected to intercritical annealing operation at 780 ° C for 360 s in a two-phase area and immediately immersed in a furnace containing molten salt bath at a temperature of 350 ° C for 600 s.

The tensile test of the samples was performed with a length of 5 cm and according to ASTM A370 standard with a speed of 1 mm/min. Then by wire cut from the middle of the fracture sample was cut to examine the cross-sectional microstructure of the sample [10].

To observe the microstructure of TRIP1100 steel, the samples were sanded and polished. Also, 2% Nital solution was used to prepare the SEM image [11]. To investigate the microstructure of TRIP steel, a JSM7001F type field emission microscope equipped with an EBSD return electron diffraction detector with TSL OIM ANALYSIS 8 analysis software was used. The samples were prepared and in the final stage, their cross section was polished with one micron diamond paste. In order to achieve a suitable surface quality for imaging, the final polishing of the samples was performed with 0.04 micron colloidal silica slurry, then a step size of 100 nm was selected for the studies. After tensile test, after failure of samples, their failure surface was examined using stereograph OLYMPUS and SEM PHILIPS XL3.

3. RESULTS AND DISCUSSION

Properties and advantages of advanced high strength steels the most important features and advantages of this type of steels can be mentioned as follows: These steels have a more complex microstructure compared to traditional steels and are mainly multi-phase to be able to have Provide a suitable and improved combination of strength and flexibility. In engineering alloys, flexibility

TABLE 1. Weight percentage of chemical composition of TRIP1100 steel used (wt%)

C%	Mn%	Si%	S%	P%	Cr%	V%	Ni%	Cu%	Al%	Fe%
0.18	2.45	1.1	0.036	0.048	0.058	0.02	0.04	0.08	0.01	Base

TABLE 2. Temperatures calculated by dilatometry

A_{C1} (°C)	A_{C3} (°C)	Calculation method
718	810	Dilatometry

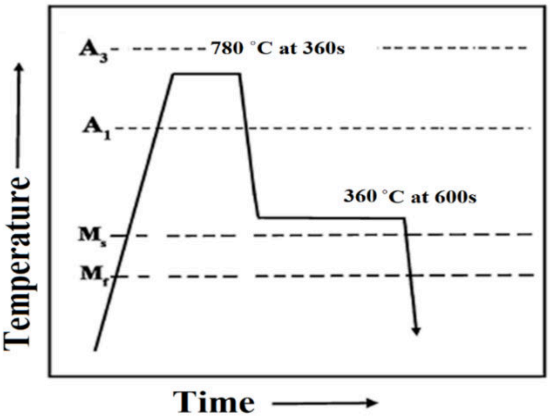

Figure 1. Schematic of TRIP steel heat treatment cycle

usually decreases with increasing strength. In other words, increasing strength is associated with decreasing toughness. We know that in high strength alloys the failure behavior tends to semi-brittle and brittle behaviors, but in steels (AHSS) the flexibility is high and as a result the probability of their failure decreases. Their high ductility makes it possible to produce specimens with complex shapes. Due to the use of different strength mechanisms and their ability to Work hardening, at the same time the strength and toughness of these alloys has been improved. Reduce the weight of the car by increasing the use of thinner and high strength steel sheets, which leads to reduced fuel consumption and reduced emissions.

Regarding advanced steels, it should be noted that a large amount of research by reputable companies has been spent annually to improve the design and use of these steels. For example, a comprehensive assessment and identification of applicable technology advances for AHSS steels was conducted in 2009. To complete the first phase in 2011, optimization of the steel structure of these steels was developed. Also, the future steel car has high hopes for the production of high-volume cars in the period 2015-2020 in phase 2 of this project. One of the attractions of this project is that for electric hybrid vehicles (PHEV), which do not discuss pollution and will soon replace current vehicles with fossil fuels, strength, vehicle speed and weight loss are of particular importance [8]. Figure 2 is a comparison of the percentage increase in the use of new steels. The key achievements of this project with regard to achieving a combination of strength and flexibility can be presented as follows:

•Achieve 29% body weight reduction
•Use of 97% HSS and AHSS steels
•Use of nearly 50% steels with a strength above 1000MPa
•Earn 5 crash safety stars
•Reduce greenhouse gas emissions

As shown in Figure 3, the microstructure of TRIP1100 steels in all directions tested includes polygonal ferrite, bainite, residual austenite (RA) and martensite/austenite (M/A) islands [12]. Due to the microstructure, residual austenite can be obtained in the bainite regions that formed during the isothermal transformation at 350 °C. Also, some residual block austenite is observed in polygonal ferrite grains [8]. In this alloy, the amount of silicon is higher than ordinary steels because the presence of silicon inhibits the formation of cementite and helps to retain all the carbon in the remaining austenite [4]. It has been shown that addition of silicon can prevent the deposition of cementite because silicon has very little solubility in cementite [13]. As austenite is further enriched by carbon in the isothermal transformation step, the onset of martensite is lower than room temperature. Therefore, part of the austenite does not convert to martensite after quenching at room temperature. This stable residual austenite is converted to martensite due to the TRIP phenomenon in the mechanically loaded steel [14].

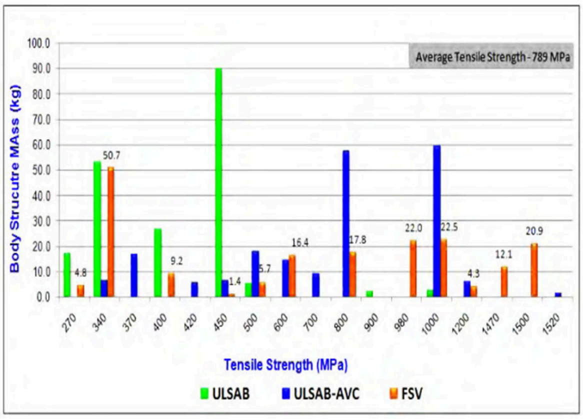

Figure 2. A comparison of the percentage increase in the use of new steels due to the increase in strength [7]

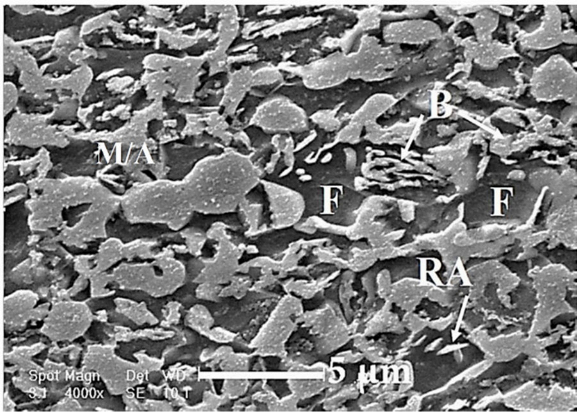

Figure 3. SEM image of TRIP steel

A more accurate knowledge of the properties is necessary to characterize the microstructure and the existing phases. For this purpose, electron diffraction analysis of EBSD return electrons was used to investigate the phase fraction. Figure 4a and b show the image of the crystal directions together with the IPF + IQ map image quality and phase fraction for TRIP1100 steel from EBSD analysis, respectively. According to Figure 4a, the size of polygonal ferrite grains was obtained between 0.5 to 4 µm and M/A phase islands between 1 and 2 µm.

The presence of residual austenite in the microstructure was determined by phase map in the range of Figure 4b, about 6.5% at the level of 50 µm. The images obtained from the phase map show the uniform distribution of the austenite remaining in the microstructure. It can be said that the remaining austenite has two block morphologies and very fine grains. The block remaining austenite forms within the M/A, while the residual austenite appears between the bainite masses as very fine grains [4]. Figure 4a shows a series of black and dark areas that have a lower IQ than the background, These areas are martensite. Martensites are darker due to lower image quality.

The stress diagram in terms of strain in the rolling direction and the average of the test results are shown in Figure 5 and Table 3, respectively. Examination of sources shows that the ratio of tensile strength (TS) to yield strength (YS) for high strength steels should not be less than 1.25 because flexibility is affected [8]. The TS/YS rate for TRIP1100 steel is more than 2.2, which indicates the steel's ability to work harder and more flexibly [5]. Table 3 shows the mechanical properties of TRIP steel.

TABLE 3. Mechanical properties of TRIP steel.

Yield strength (MPa)	**Ultimate tensile strength (MPa)**	**Elongation (%)**	**Hardness (HV)**
501 ± 12	1150 ± 13	23 ± 1	336 ±12

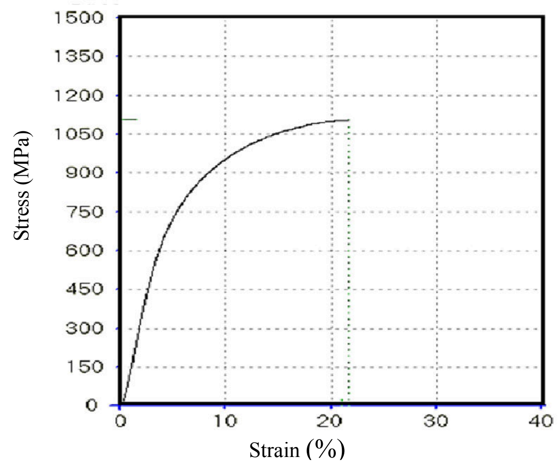

Figure 5. Stress diagram in terms of TRIP steel engineering strain in the rolling direction

To investigate the type of fracture of TRIP1100 steel, failure analysis was performed after tensile test. In TRIP1100 steel, fractures were detected with almost coaxial dimples and the bruises contained impurities that caused fracture and spread the crack during plastic deformation [14]. Figure 6 shows the SEM image of the TRIP1100 steel fracture surface. The present steel contains brittle and soft phases next to each other, therefore at the fracture surface, soft breakage and brittle failure are observed [15]. Cleavage failure, which had a lower percentage of failure surface than existing dimples, is indicated in Figure 6 by the arrow.

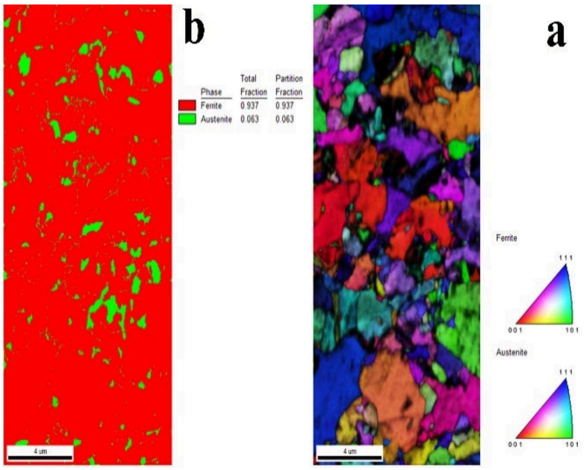

Figure 4. (a) Crystal image and IPF image quality map + IQ MAP, b) Fuzzy fraction of steel in the direction of TRIP rolling from EBSD results

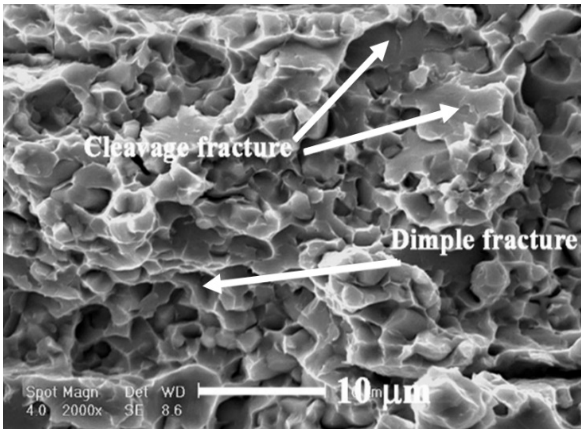

Figure 6. SEM image of TRIP1100 steel fracture surface, arrows represent dimples and cleavage failure

4. CONCLUSION

The microstructure of TRIP1100 steels in all directions tested includes polygonal ferrite, bainite, residual austenite (RA) and martensite/austenite (M/A) islands. According to the microstructure, residual austenite can be obtained in the bainite regions that formed during the isothermal transformation at 350 °C.

1. The presence of residual austenite in the microstructure was determined by phase map in the range of Figure 5b, about 6.5% at the surface of 50 µm. The images obtained from the phase map show the uniform distribution of the austenite remaining in the microstructure. It can be said that the remaining austenite has two block morphologies and very fine grains. The block remaining austenite forms within the M/A, while the residual austenite appears between the bainite masses as very fine grains.
2. The SEM image shows the failure surface of TRIP1100 steel. The present steel contains brittle and soft phases next to each other, due to at the fracture surface, soft failure and brittle failure are observed. Cleavage failure had a lower percentage of failure surface than existing dimples.
3. The TS/YS rate for TRIP1100 steel is more than 2.2, which indicates the steel's ability to work harder and more flexibly.

5. REFERENCES

1. "Specification for automotive weld quality- resistance spot welding of steel", AWS, (2007).
2. M. Pouranvari, S. P. H. Marashi and Safanama, D.S., "Failure mode transition in ahss resistance spot welds. Part ii: Experimental investigation and model validation", ***Materials Science and Engineering A***, Vol. 528, No. 29–30, doi: 10.1016/j.msea.2011.08.016
3. Jung, G., Lee, K., Lee, J., Bhadeshia, H., Suh, D.J.S., Welding, T.o. and Joining, "Spot weldability of trip assisted steels with high carbon and aluminium contents", ***Science and Technology of Welding and Joining***, Vol. 17, No. 2, (2012), 92-98, doi: 10.1179/1362171811Y.0000000081
4. Amirthalingam, M., "Microstructural development during welding of trip steels", (2010).
5. Zum Mallen, R., Tarr, S. and Dykeman, J., "Recent applications of high strength steels in north american honda production", in Great Designs in Steel Conference. (2008).
6. Pan, J., Sripichai, K., Lin, P., Wang, D. and Lin, S., Mechanics modeling of spot welds under general loading conditions and applications to fatigue life predictions, in Failure mechanisms of advanced welding processes. (2010), Elsevier.1-23.
7. Matsushita, M., Ikeda, R. and Oi, K.J.W.i.t.W., "Development of a new program control setting of welding current and electrode force for single-side resistance spot welding", ***Welding in the World***, Vol. 59, No. 4, (2015), 533-543, doi: 10.1007/s40194-015-0228-1
8. Pouranvari, M., Marashi, S.J.M.S. and A, E., "Failure mode transition in ahss resistance spot welds. Part i. Controlling factors", ***Materials Science and Engineering A***, Vol. 528, No. 29-30, (2011), 8337-8343, doi: 10.1016/j.msea.2011.08.017
9. Pouranvari, M., Marashi, S.J.S., welding, T.o. and joining, "Critical review of automotive steels spot welding: Process, structure and properties", ***Welding and Joining***, Vol. 18, No. 5, (2013), 361-403, doi: 10.1179/1362171813Y.0000000120
10. Tamarelli, C.M.J.S.M.D.I., Michigan, "The evolving use of advanced high-strength steels for automotive applications", Steel Market Development Institute, (2011).
11. Mikno, Z., Stepien, M. and Grzesik, B.J.W.i.t.W., "Optimization of resistance welding by using electric servo actuator", ***Welding in the World***, Vol. 61, No. 3, (2017), 453-462, doi: 10.1007/s40194-017-0437-x.
12. Hajiannia, I., Ashiri, R., Pakmanesh, M., Shamanian, M. and Atapour, M.J.J.o.E.F.M., "Evaluation of performance of resistance spot welded joints with different parameters in advanced high strength trip steel", ***Journal of Environmental Friendly Materials***, Vol. 3, No. 1, (2019), 9-16, doi:
13. Pouranvari, M., Mousavizadeh, S., Marashi, S., Goodarzi, M., Ghorbani, M.J.M. and Design, "Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of aisi 1008 low carbon steel and dp600 advanced high strength steel", ***Materials & Design***, Vol. 32, No. 3, (2011), 1390-1398, doi: 10.1016/j.matdes.2010.09.010
14. Emre, H.E. and Kaçar, R., "Development of weld lobe for resistance spot-welded trip800 steel and evaluation of fracture mode of its weldment", ***The International Journal of Advanced Manufacturing Technology***, Vol. 83, No. 9-12, (2016), doi: 10.1007/s00170-015-7605-1
15. Kim, C.-H., Choi, J.-K., Kang, M.-J., Park, Y.-D.J.J.o.A.i.M. and Engineering, M., "A study on the co2 laser welding characteristics of high strength steel up to 1500 mpa for automotive application", ***Journal of Achievements***, Vol. 39, No. 1, (2010), 79-86.

Persian Abstract

چکیده

در این پژوهش به بررسی عملیات حرارتی و تولید فولاد فوق استحکام بالای پیشرفته TRIP1100 پرداخته شد و سپس به ارزیابی خواص مکانیکی جوش های این فولاد که توسط نقطه‌ای انجام شده بود پرداخته شده است. برای این منظور تأثیر فرآیند نورد و عملیات حرارتی ورق های فولادی آلیاژ سازی شده جهت دستیابی به ریزساختار فولاد TRIP1100 فوق استحکام بالای پیشرفته پرداخته شد. بررسی های ریزساختاری توسط میکروسکوپ الکترونی روبشی زمینه فریت با فازهای بینیت، مارتنزیت را مشخص کرد. مشخصات میکروساختاری با استفاده از میکروسکوپ SEM با آنالیز EBSD، بررسی شدند. نتایج EBSD نشان داد، نوع و جهت‌گیری دانه ها تغییر کرده و کسر مرزهای با زاویه زیاد به زاویه کم در فولاد حاضر به دلیل وجود فاز های مختلف متغیر و فراوانی دارد، نتایج EBSD میزان مورد قبولی آستنیت اولیه را در ساختار با توجه به فاز شناسی این روش نمایش داد. دارا بودن خواص مکانیکی مطلوب از مهم ترین نتایج این پژوهش بود که همزمان ضربه پذیری و استحکام مکانیکی حفظ شد.