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Microstructure, microhardness and tensile properties of FSWed DP 800 steel

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ABSTRACT

Purpose: Dual phase (DP) steels are widely used in the automotive industry due to their properties of a high balance of strength and formability. However, it is known that conventional welding of high strength steel leads to some undesirable results such as hardness decrease in the heat affected zone. Friction stir welding (FSW) is a new solid state joining method, which is used to join these steels due to its advantage of low heat input. The aim of this study is to evaluate the microstructural change and mechanical properties of friction stir welded DP800 steel.

Design/methodology/approach: DP 800 steels with 1.5 mm thickness were subjected to friction stir welding, by using a tungsten carbide (WC) tool. The tool was tilted 2°, and downforce of the tool was kept constant at 6 kN. During processing, the tool rotation and traverse speed were fixed at 1600 rpm and 170 mm·min^{-1}, respectively.

Findings: The friction stir welded region comprises martensite, bainite, refined ferrite. The average microhardness of stir zone has increased from 260 HV0.2 to about 450 HV0.2. The tensile sample shows a decrease in the ultimate tensile strength (σUTS) about 3%, from 827 MPa to 806 MPa for the joint. The yield strength (YS) of the joint is about 566 MPa and the value is near that of DP800.

Research limitations/implications: The tungsten carbide tool used for the friction stir welding has suffered deterioration in the pin profile after 1 meter welding operation. It may be advisable to drill a pre-hole in the specimens for a longer tool life.

Practical implications: Tool wear for industrial applications will be a major problem. Therefore, the use of tools with high wear resistance such as polycrystalline cubic boron nitride may be recommended.

Originality/value: Works on friction stir welding of dual phase steels are limited and they mostly focus on spot welding. Also, this study systematically investigates the microstructure and mechanical properties of dual-phase 800 steels after the friction stir welding.

Keywords: Friction stir welding; DP 800 steel; Microstructure and mechanical properties

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PROPERTIES

1. Introduction

Dual phase (DP) steels are characterized by a microstructure consisting of ferrite and martensite. Their strain hardening at low strains is very fast, has low yield strength (YS), a ultimate tensile strength (UTS) and therefore a low YS/UTS high ratio [1]. High strength and good ductility properties of DP steels have led to their widespread use in automotive sheet metal forming processes [2]. Also, many automotive applications such as door panels, roofs and pillars require the welding of dual-phase steels [3]. However, it is known that conventional welding of high strength steel such as DP steels suffered from softening in the heat affected zone [4].

Friction stir welding (FSW) is well known as a new solid state welding method which is used to join similar and dissimilar kind of materials [5]. During FSW, distortion and residual stresses in the steel structure are limited and grain growth is kept at the lowest level in the heat affected zone (HAZ) due to the low heat input [6,7]. Therefore, the researchers have focused on the welding of steel with this method.

The works on the friction stir welding of the DP steels are very limited and most of them are on the friction stir spot welding [8-13] and very little on the friction stir butt welded [14,15]. However, the effect of FSWed on the microstructural evolution, microhardness and also strength properties of the DP 800 steel has not been investigated systematically. Therefore, the main purpose of this study is to investigate microstructural and mechanical properties of FSWed DP 800 steel.

2. Materials and methodology

Galvanize coat in the DP 800 steel sheet is removed by using acid solution before FSW. For FSW, the plates having dimensions of 200 mm x 50 mm x 1.5 mm were produced from the DP 800 steel sheets. FSW was performed by using a tungsten carbide (WC) tool with a shoulder diameter of 14 mm, a conical pin with the diameter of 5 mm having angle of 30° and length of 1.3 mm. During the experiments, the tool rotation and traverse speeds were fixed at 1600 rpm and 170 $mm \cdot min^{-1}$, respectively. The tool was tilted 2°, and downforce of the tool was kept constant at 6 kN. Optical microscope (OM) and scanning electron microscope (SEM) were used to observe the microstructure of FSWed region.

Samples for the tensile test and metallographic investigation were sectioned perpendicular to the welding direction of the plate by wire-EDM technique (Fig. 1), polished with standard techniques and then etched in 2% Nital (2 ml HNO_3 + 98 ml C_2H_6O) for 20 s. Tensile tests were performed using dog-bone shaped tension samples with the dimensions of 1.4 mm x 5 mm x 35 mm that were machined from the welded region (Fig. 1). The tests were performed using an Instron-3382 electro-mechanical load frame with a video type extensometer at a strain rate of $2.8 \cdot 10^{-4}$ s^{-1}. Hardness measurements were performed using a Vickers micro-hardness tester, operated at HV0.2.

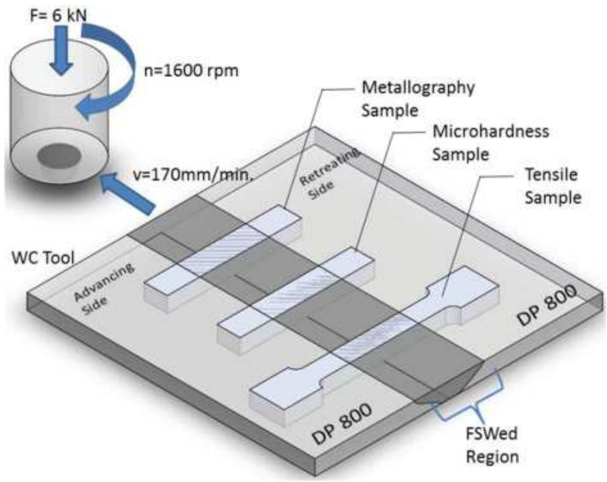

Fig. 1. Schematic illustration of the FSWed DP800 steel and the specimen's positions and shapes inside the FSWed regions

3. Results and discussion

3.1. Microstructure

A general macro-view of cross-section of FSWed DP 800 steel joint and microstructural changes of FSWed region are shown Fig. 2a-e. No micro voids and defects in the FSW region have been observed (Fig. 2a). The microstructure of FSWed region is comprised of complex microstructures such as martensite islands, lath martensite, tempered martensite, bainite and ferrite. The DP 800 steel has a typical dual phase steel structure consisting of ferrite grain (F) and martensite islands (MI) as shown in Fig. 2b. The base material has a volume fraction of martensite of 45% and an average ferrite grain size of 4 μm The SEM micrographs shown in Fig. 2c clearly showed that almost all of the microstructure (≈99%) in the SZ is formed of lath martensite (LM). Stir zone (SZ) undergoes both severe plastic deformation and frictional heating due to the rotational tool during FSW. Thus, the microstructural change exhibits a quite different characteristic in the SZ contrary to expectations. Ohashi et al. [11] reported that the DP 590 steel formed full martensite at the microstructure in the SZ during the friction stir spot welding. Figure 2d shows that the microstructure in SZ near the HAZ is converted to bainite. This change may be due to the decrease in temperature and the effect of deformation. Depending on the cooling rate, the austenite transforms back into acicular products, bainite or martensite [16]. The microstructure of HAZ is formed tempered martensite which consist of very small and uniformly dispersed cementite [17]. Tempered martensite partially decomposing cementite and ferrite in the HAZ is seen from Fig. 2e.

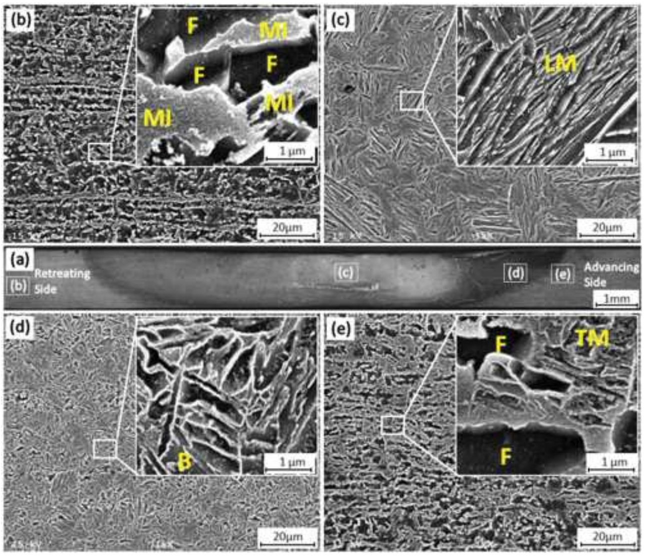

Fig. 2. a) A general macro-view of the cross-section of FSWed DP 800 steel joint. Selected SEM micrographs showing the: b) DP 800 base material, c) stir zone (SZ), d) transition region to the heat affected zone (HAZ) in SZ on advancing side, e) HAZ on advancing side.(where MI: martensite island, LM: lath martensite, TM: tempered martensite, B: bainite and F: ferrite)

3.2. Microhardness

Microhardness profiles of the FSWed samples through the vertical and longitudinal sections are shown in Fig. 3a-c. DP 800 steel exhibited microhardness values of about 260 HV0.2. Longitudinal microhardness measurements are carried out at 0.8 millimetres under the welding surface. The highest microhardness value is 510 HV0.2 and this microstructure consists of lath martensite structure. Microhardness decreased in transition region to in the SZ of near HAZ. This region microhardness is about 450 HV 0.2 having bainitic microstructure. Tempered martensite microstructure in the HAZ caused an 8% decrease in microhardness value. The reduction in hardness in the HAZ is very low compared to fusion and laser welding [16,18]. Such increase in hardness of the SZ may be considered as an expected result of the grain refinement as well as lath martensite. Also, an increase in dislocation density induced by intensive plastic deformation is also effective in the enhancement of hardness.

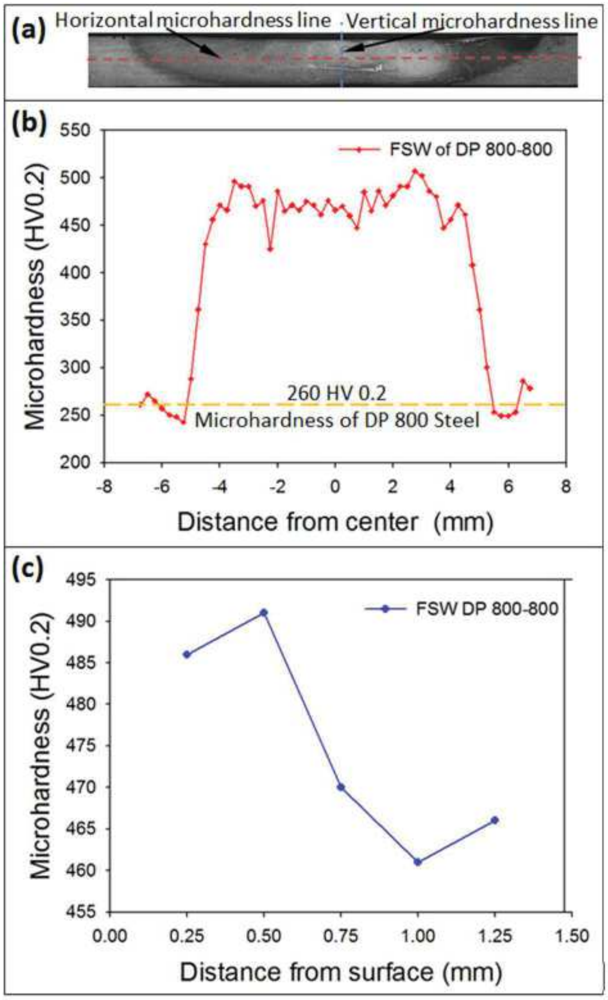

Fig. 3. a) Optical micrographs showing the cross-sectional view of FSWed DP 800 joints, b) longitudinal hardness profiles, c) vertical hardness profiles cross-sections of the FSWed sample

3.3. Tensile properties

The engineering stress- strain curves of the base DP 800 steel and after FSWed joints are shown in Fig. 4, and the values of strength and ductility that obtained from these curves are given in Table 1.

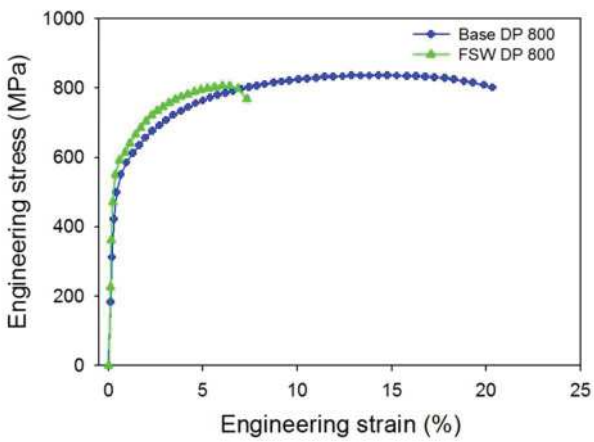

Fig. 4. Stress-strain curves of the Base DP 800 steel and FSWed DP 800 steel joint

Table 1.
Main strength and ductility values of DP 800 steel and FSWed joints

Sample	σ_Y, MPa	σ_{UTS}, MPa	ε_u, %	ε_f, %
DP 800	527	827	17	21
FSWed	566	806	6	8

The base DP 800 sample showed a high elongation with a very large tensile hardening region as a typical characteristic of dual phase steels (Fig. 4). The yield strength (σ_y) and ultimate tensile strength (σ_{uts}) of the base DP 800 steel are 527 MPa and 827 MPa, respectively. The stress-strain curve of the FSWed joint sample characteristically resembles the base DP 800 steel. The yield strength of the FSWed joint sample was determined to be 566 MPa with an increase of 7% and the tensile strength to 806 MPa with a reduction of 3%. The uniform and total elongation of the base DP 800 steel is about 17% and 21%, respectively. After FSW, these values decreased down to about 6% and 8%, respectively. The reason for this is that the softening of the HAZ has caused the first neck to appear in this region. Furthermore, since the hardness of the FSWed zone is higher than the base material, the strain length contributing to the total elongation is only the base material, which is considered to cause the elongation values to be decreased.

4. Conclusions

In the present study, the microstructure, microhardness hardness profile and tensile properties of FSWed DP 800 steel was investigated. The main results and conclusions of this study can be summarized as follows:

- After the friction stir welding, the microstructure showed lath martensite, bainite, refined ferrite and tempered martensite.
- The highest hardness with 510 HV0.2 was observed in the lath martensite microstructure in the SZ, while the lowest hardness with 250 HV0.2 was observed in the tempered martensite microstructure in the HAZ.
- The strain stress curves of FSWed sample characteristically resemble the base material and no significant change in strength values is observed. However, a significant decrease in ductility values has occurred. It is considered that this is caused by the fact that the welding region does not contribute to the total elongation.

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References

[1] M.S. Rashid, Dual Phase Steels, Annual Review of Materials Science 11/1 (1981) 245-267, doi: 10.1146/annurev.ms.11.080181.001333.

[2] C.C. Tasan, M. Diehl, D. Yan, M. Bechtold, F. Roters, L. Schemmann, C. Zheng, N. Peranio, D. Ponge, M. Koyama, K. Tsuzaki, D. Raabe, An Overview of Dual-Phase Steels, Advances in Processing and Micromechanically Guided Design 45 (2015) 391-431.

[3] W.D. Antunes, M. Sergio, F. De Lima, Experimental development of dual phase steel laser-arc hybrid welding and its comparison to laser and gas metal arc welding, Soldagem & Inspeção 21 (2016) 379-386.

[4] M. Ghosh, K. Kumar, R.S. Mishra, Friction stir lap welded advanced high strength steels: Microstructure and mechanical properties, Materials and Science Engineering A 528 (2011) 8111-8119.

[5] R.S. Mishra, M.W. Mahoney (Eds.), Friction Stir Welding and Processing, ASM International, 2007, 368, doi: 10.1361/fswp2007p001.

[6] H. Fujii, L. Cui, N. Tsuji, M. Maeda, K. Nakata, K. Nogi, Friction stir welding of carbon steels, Materials and Science Engineering A 429 (2006) 50-57.

[7] G. Cam, S. Mistikoglu, Recent developments in friction stir welding of Al-alloys, Journal of Materials Engineering and Performance 23 (2014) 1936-1953.

[8] M. Santella, Y. Hovanski, A. Frederick, G. Grant, M. Dahl, Friction stir spot welding of DP780 carbon steel, Science and Technology of Welding and Joining 15 (2010) 271-278.

[9] N. Saunders, M. Miles, T. Hartman, Y. Hovanski, S.-T. Hong, R. Steel, Joint strength in high speed friction stir spot welded DP 980 steel, International Journal of Precision Engineering and Manufacturing 15 (2014) 841-848.

[10] M.I. Khan, M.L. Kuntz, P. Su, A. Gerlich, T. North, Y. Zhou, Resistance and friction stir spot welding of DP600: a comparative study, Science and Technology of Welding and Joining 12 (2007) 175-182.

[11] R. Ohashi, M. Fujimoto, S. Mironov, Y.S. Sato, H. Kokawa, Effect of contamination on microstructure in friction stir spot welded DP590 steel, Science and Technology of Welding and Joining 14 (2009) 221-227.

[12] G.M. Xie, H.B. Cui, Z.A. Luo, W. Yu, J. Ma, G.D. Wang, Effect of rotation rate on microstructure and mechanical properties of friction stir spot welded DP780 steel, Journal of Materials Science and Technology 32 (2015) 326-332.

[13] Z. Feng, M.L. Santella, S.A. David, R.J. Steel, S.M. Packer, T.-Y. Pan, M. Kuo, R.S. Bhatnagar, Friction stir spot welding of advanced high-strength steels – a feasibility study, SAE Technical Paper 2005-01-1248, 2005, doi:10.4271/2005-01-1248.

[14] M.P. Miles, J. Pew, T.W. Nelson, M. Li, Comparison of formability of friction stir welded and laser welded dual phase 590 steel sheets, Science and Technology of Welding and Joining 11 (2006) 384-388.

[15] Y.G. Kim, J.S. Kim, I.J. Kim, Effect of process parameters on optimum welding condition of DP590 steel by friction stir welding, Journal of Mechanical Science and Technology 28 (2014) 5143-5148.

[16] A.M.A. Pazooki, M.J.M. Hermans, I.M. Richardson, Finite element simulation and experimental investigation of thermal tensioning during welding of DP600 steel, Science and Technology of Welding and Joining 22/1 (2017) 7-21.

[17] W. Xu, D. Westerbaan, S.S. Nayak, D.L. Chen, F. Goodwin, E. Biro, Y. Zhou, Microstructure and fatigue performance of single and multiple linear fiber laser welded DP980 dual-phase steel, Materials and Science Engineering A 553 (2012) 51-58.

[18] N. Farabi, D.L. Chen, Y. Zhou, Microstructure and mechanical properties of laser welded dissimilar DP600/DP980 dual-phase steel joints, Journal of Alloys and Compunds 509 (2011) 982-989.