Materials and Design 56 (2014) 193–199

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Tensile properties of fiber laser welded joints of high strength low alloy and dual-phase steels at warm and low temperatures

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ARTICLE INFO

Article history:
Received 27 August 2013
Accepted 30 October 2013
Available online 9 November 2013

Keywords:
Fiber laser welding
Dissimilar joint
High strength low alloy steel
Dual-phase steel
Tensile
Temperature

ABSTRACT

High strength low alloy (HSLA) and dual-phase DP980 (UTS ⩾ 980 MPa) steels were joined using fiber laser welding in similar and dissimilar materials combinations. The welded joints were characterized with respect to microhardness and tensile properties at three different temperatures: −40 °C, 25 °C, and 180 °C. Tensile properties of the welded joints were compared to those of the base metal (BM) obtained under similar conditions. A good correlation was found between the welded joints and the BM in relation to the tensile properties obtained at the different temperatures. A general trend of increase in the yield strength (YS), the ultimate tensile strength (UTS) and energy absorption (EA) with decreasing temperature was observed; however, work hardening coefficient was not altered and insignificant scatter was observed in case of the elongation. However, in the DP980 steel, dynamic strain ageing was observed only in the BM.

1. Introduction

In order to reduce the volume of CO_2 emission into the atmosphere, a significant increase in the fuel efficiency of the vehicles is required [1–3]. Therefore, automotive manufacturers are continuously looking for methods to achieve this goal. One of the popular methods to increase the fuel efficiency is to use the auto-body parts made of stronger materials, which will help in down-gauging leading to decrease in the vehicle weight [2,3]. Advanced high strength steel (AHSS) is a family of such materials, thinner sheets of which can replace conventional thicker materials used in auto-body structures i.e. low carbon steel, interstitial free steel or high strength low alloy steel (HSLA) steel, without compromising crashworthiness because of their higher strength and good formability [4–6]. Dual phase (DP) steel is one of the popular AHSS that is being increasingly used in the automotive industries [6]. Currently, several grades of DP steel are being considered for certain parts of auto-body where higher strength is necessary, e.g., B-pillars and bumpers [7] that were previously made of HSLA steel.

Welding is the primary joining process in automotive industry; therefore, lots of work has been done on the weldability, microstructure, and performance of AHSS in order to determine their implementation in current and future cars [8–13]. CO_2, Nd:YAG, and recently fiber laser are used for manufacturing laser welded blanks (LWBs), also known as tailor welded blanks, which are formed into different required three dimensional auto-body parts [14]. Among all laser welding processes, fiber laser welding (FLW) has been shown recently [8–10] to provide improved tensile and fatigue properties for the DP980 steel welded joints because of the possibility to reduce the size of the weld zones. In addition, FLW has several other advantages e.g. smaller beam size, lower maintenance costs, higher efficiency, high precision and reliability, and low space requirements due to compact design [14]. Considering the applicability in the auto industry, several studies have been done in last decades to investigate the effects of different welding processes on the microstructure and mechanical properties of the DP steel welded joints [8–12]. A common conclusion, which all these studies reported, was the softening, which occurs in the sub-critical heat affected zone (HAZ) where temperature experienced by the work piece is close to or below Ac_1 line [8–13]. Softening is associated with tempering of the martensite leading to a drop in the hardness below that of the base metal (BM) [8–10,12,13] and deterioration in the performance of the DP steel welded joints [8–13].

Although DP steels are emerging candidates, the major parts of the cab body are still dominated by HSLA steel. Considering this, researchers have been interested in and studied the microstructure and mechanical properties of the similar and dissimilar welded joints between HSLA and DP980 steels [8–13]. There are also reports on the effects of temperature on the mechanical properties of DP980 steels [15–20]. However, there is no report on the

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http://dx.doi.org/10.1016/j.matdes.2013.10.087

Table 1
Chemical composition of the DP980 and HSLA steel investigated (wt.%).

Steel	C	Mn	Si	Al	Cr	Ni	N	Fe
DP980	0.15	1.45	0.33	0.05	0.02	0.01	0.009	Balance
HSLA	0.08	0.83	0.5	0.05	0.03	0.01	0.007	Balance

mechanical behavior of the welded joints of HSLA and DP980 steels at low and warm temperatures, which is important to investigate considering the environmental conditions to which vehicles are exposed. The present study was carried out to fill the gap in the literature and reports the mechanical properties of the fiber laser welded joints of DP980 and HSLA steels in similar and dissimilar materials combinations evaluated at cryogenic, room and elevated temperatures.

2. Experimental procedure

Hot dip galvanized (GI) sheets of DP980 and HSLA steels with a thickness of 1.2 mm were used in this study. The chemical compositions and the microstructure of the steels are given in Table 1 and Fig. 1, respectively. HSLA contained a fine grained ferritic matrix dispersed with ultra-fine alloyed carbides. DP steels have a ferritic matrix embedded with islands of martensite (∼56%).

The steel sheets were sheared into 100 mm × 200 mm coupons, which had the sheared edges placed together for running welds in butt joint configuration to make 200 mm × 200 mm LWBs, as shown in Fig. 2(a). Welding was done perpendicular to the rolling direction of the sheets in an IPG Photonics YLS-6000 fiber laser system using a power and speed of 6 kW and 16 m/min, respectively. The laser had a beam focal length of 20 cm, and a spot size of 0.6 mm. The core diameter of the fiber laser was 0.3 mm. Welding was performed with a head angle of 0° and no shielding gas was used during the welding process [13].

Microstructure study was done on the weld cross-sections, which were prepared following standard metallographic procedure e.g. mounting, grinding, polishing using 1 μm diamond suspension followed by etching with 2% Nital solution. The optical microscopy and scanning electron microscopy (SEM) study on the etched specimens was performed using a Nikon Epiphot light microscope equipped with Clemex image analysis software and JEOL JSM-6380 scanning electron microscope equipped with Oxford energy dispersive X-ray spectroscopy (EDS), respectively. Etched specimens were also used to obtain the Vickers microhardness profiles across the welded joints using a Buehler micromet 5103 computerized microhardness tester using a 200 g load for 15 s dwell time. The microhardness indentations were spaced sufficiently apart to prevent interference from the localized strain hardening from the adjacent indentations. To ensure the validity of the microhardness measurements, calibration was done on a standard specimen.

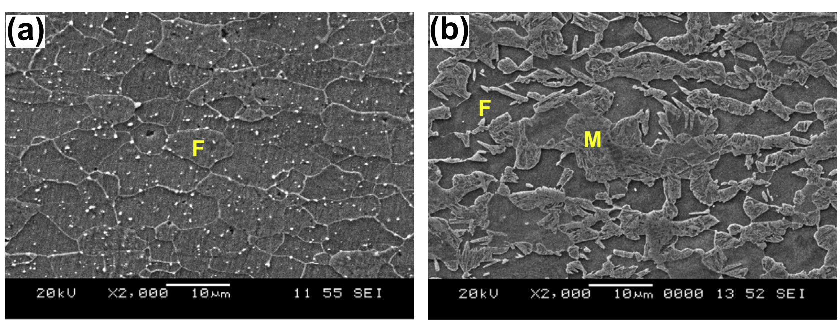
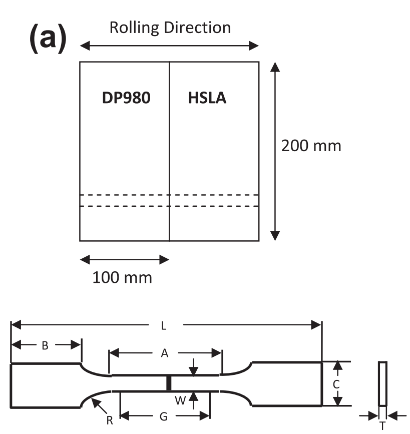


Fig. 1. Microstructure of HSLA-DP980 weld at RT (a) HSLA BM, (b) DP980 BM. (F: ferrite, M: martensite).



(b)

Position	G	W	R	L	A	B	C	T
Dimension (mm)	50	12.5	12.5	200	57	50	20	1.2

Fig. 2. Schematic diagram illustrating (a) the gometry of the fiber laser welded joint, (b) a transverse tensile specimen of the FLWedweld obtained machinedalong the dashed lines in (a).