Materials and Design 52 (2013) 757–766

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Effects of weld line position and geometry on the formability of laser welded high strength low alloy and dual-phase steel blanks

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ARTICLE INFO

Article history:
Received 26 October 2012
Accepted 9 June 2013
Available online 19 June 2013

Keywords:
Laser welded blank
Advanced high strength steel
Formability
Hardness

ABSTRACT

Formability of laser welded blanks (LWBs) was measured in the biaxial stretch forming mode using the limiting dome height (LDH) test. High strength low alloy steel and two dual-phase (DP600 and DP980) steels were used for fabricating LWBs. The failure location and the LDH values of the formed blanks were correlated to the hardness across the welds. The effects of weld line position and geometry on the formality was evaluated by investigating LWBs with three different weld line positions (0, 15 and 30 mm offsets from the blank center) for both linear and curvilinear geometry. The formability was found to be dependent on the weld line position and increased when the weld was located farther from the blank center due to more uniform strain developed during LDH tests. Interestingly, weld line geometry was observed to have a stronger influence on the formability DP600 steel. In addition to weld line position and geometry, heat affected zone softening was observed to be the dominant factor in controlling the formability of all the DP980 LWBs and the curvilinear welds of DP600 with failure consistently occurring in the region with more severe softening.

1. Introduction

The continuous growth in environmental and economic concerns has pushed automotive manufacturers to implement innovations to reduce vehicle emission, improve fuel economy without compromising the safety, structural integrity and crash performance of the vehicle. One of the ways the auto makers have been trying to resolve above mentioned issues is by increasing the use of laser welded blanks (LWBs) in car body structure. LWBs are composed of two or more sheets of similar or dissimilar materials, thicknesses and/or coating types welded together. These composite blanks are then stamped to form the required three dimensional automotive body parts [1]. The advantages of LWBs include weight reduction, cost minimization, and scrap reduction with improved steel utilization. Typically, LWBs are made with low or ultralow carbon steels; however, their weight reduction ability can further be increased by employing high strength steels like high strength low alloy (HSLA) steel and even more so by advanced high strength steels (AHSS) which also improves the crash performance of the blanks [1–4].

AHSS family includes wide variety of steels such as dual-phase (DP) steel, transformation induced plasticity (TRIP) steel, complex phase steel, martensitic steel and twinning induced plasticity (TWIP) steel, which are categorized based on the microstructure and processing history. AHSS has superior ultimate tensile strength and excellent formability compared to HSLA and is able to form complex shapes due to its high strain hardening behavior [5]. These characteristics make AHSS a potential candidate for manufacturing energy absorbing components for vehicles [5,6]. Amongst all AHSS, DP steel is of particular interest due to the optimum combination of strength and formability, which is attributed by its unique microstructure consisting of a continuous soft/ductile ferrite matrix embedded with hard martensitic phase. Although DP steels have several advantages, they exhibit heat affected zone (HAZ) softening when welded, which occurs at the sub-critical region of the HAZ due to tempering of martensite in the base metal (BM). The HAZ softening phenomenon has been known to result in reduction of the local hardness below that of the BM [7–9], which is more significant in the higher grades (UTS $\geqslant$ 800 MPa) of DP steels [10,11]. HAZ softening has been reported to degrade the performance of the DP steel welds [12–17]. For example, the tensile strength and ductility of the DP steel LWBs decreases because of HAZ softening [12,13], with increase in softening and width of the soft zone reduces the strength and ductility further as reported by Panda et al. [14]. Lap-shear tensile strength of the DP steel spot welds have also been observed to reduce with increase in softening due to premature failure in the soft zone, as reported by Okita et al.

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0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.06.021

[10] and Ghosh et al. [15]. Furthermore, recently Xu et al. [16] and Parkes et al. [17] have reported that the HAZ softening reduces the fatigue resistance of the DP980 steel with a decrease in softening improved the fatigue performance [18].

The formability of the LWBs have been an important subject for the researchers as can be observed from the studies reported so far; such as clarifying fundamental formability characteristics of LWB [3], methods of evaluating formability of the LWBs in punch stretching, stretch flanging and deep drawing [4]. There are also reports on the effect of the weld design on the formability of LWBs for different material combinations such as dissimilar thickness or strength ratios [19–22] and weld line movement in dissimilar materials combination [23]. For instance, Chan et al. [19] observed that increasing the strength ratio of the LWBs resulted in decrease in the formability and forming limit curve. Like the tensile and fatigue properties, HAZ softening reduces the formability of laser welded DP steels because of the strain localization in this region leading to premature failure in the forming process [20–24]. It has also been reported that the detrimental effect of HAZ softening can be reduced by increasing the welding speed (i.e. lowering the heat input), which decreases the softened zone width as a result of less severe martensite tempering, hence improving the mechanical properties [14,18] and formability of the DP steel LWB [21,26,27–29]. For example, tensile strength close to the BM was observed when higher welding speed was used [18], the soft zone width was found to increase with increasing welding speed resulting in improved strength and ductility [14]. Sreenivasan et al. [21] concluded that higher welding speed in Nd:YAG laser resulted in an improved formability compared to lower speed used in diode laser. Friction stir welding has been reported to result in 20% higher formability compared to CO_2 laser welding in DP590 steel [29]. In another study, Padmanabhan et al. [30] have reported the effects of anisotropy on the forming behavior of mild steel-DP steel welded blanks and they concluded that by controlling the anisotropy, formability can be improved. However, the effect of anisotropy was not beneficial when applied to DP steel welded blanks, where the HAZ softening dominates formability [30]. Another successful attempt to improve formability of DP steel was by fabricating dissimilar LWBs with HSLA steel [23]. Additionally, there were also attempts on varying the weld line positions in dissimilar welded blanks; wherein it was observed that the formability increases due to improved uniform strain distribution on the deformed blank when the weld line is placed farther from the center of the blank [22,30,32,33].

Recently, the effects of seam radius (i.e. radius of curvature of the weld) and thickness ratio [34,35]; and the influence of blank size [35] on the forming behavior of curve seam welded blanks on formability have been reported. However, there is lack of reports on the comparison of the effects of curved and linear weld line positions on forming behavior of LWBs. Thus, the present study aimed to investigate the effects of weld line position and geometry on the formability of laser welded HSLA and DP steel blanks considering this will facilitate the understanding of the influence of weld design on the forming behavior of LWB involving these automotive steels.

2. Experimental details

In the present study, three steel sheets were chosen to manufacture LWBs: HSLA (high-strength low-alloy) steel, DP600 and DP980 dual-phase steels (both are AHSS) with nominal thickness of 1.14 mm, 1.2 mm and 1.2 mm, respectively. The BM microstructure of HSLA steel contains a ferrite matrix decorated with fine alloy carbides, whereas DP steels consist a mixed microstructure containing continuous ferrite matrix and martensite islands (26% in DP600 and 54% in DP980) as shown in Fig. 1 [32]. The mechanical properties of the steels are given in Table 1. These materials were chosen because of their applications in the automotive industry as structural materials, and in rails and pillar components to enhance crash performance [4,5].

To fabricate LWBs the steel sheets were sheared in to 200 mm × 200 mm coupons. The steel coupons were clamped tightly with a specially designed fixture alignment intact and to minimize distortion during welding. This custom fixture had a widened back shielding gap to accommodate the weld curvature and an inlet for the back shielding gas to enter. A Nuvonyx ISL-4000L High Power Diode Laser head mounted on a Panasonic VR-16 robotic arm was used for welding. The laser beam was aligned with the guide lines drawn on the blanks prior to welding. The laser beam had a rectangular spot (12 mm × 0.9 mm) and a focal length of 80 mm. Welding was carried out using 4 kW power and a welding speed of 0.85 mm/min in the bead-on-plate orientation. All the welds were made perpendicular to the rolling direction with the weld line located at 0 mm, 15 mm and 30 mm from the center of the blank. In case of curvilinear weld geometries, welds were made with a curvature of 220 mm as illustrated in Fig. 2; showing the naming convention of the blank. The left side of the

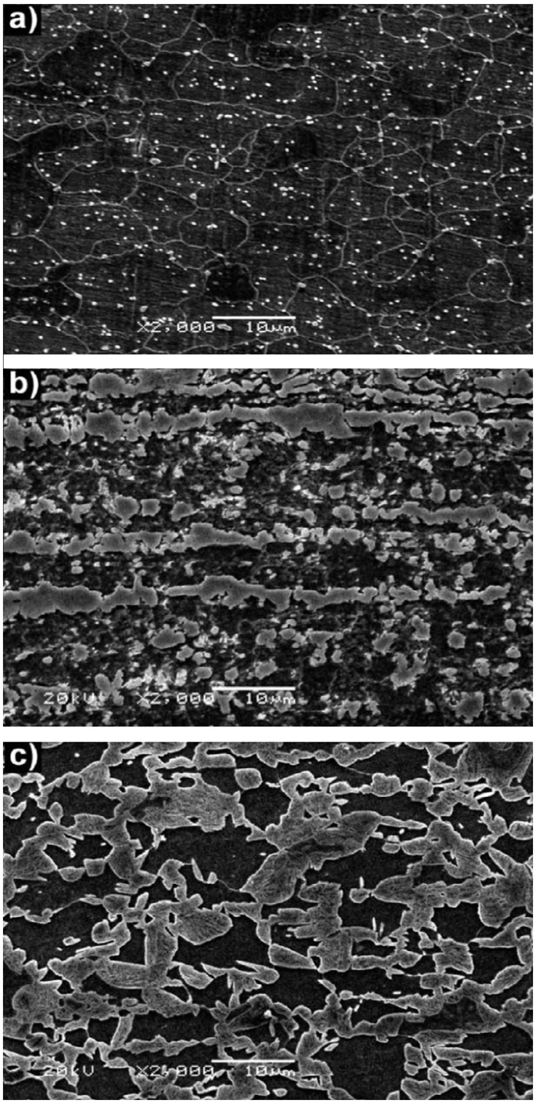

Fig. 1. Base metal microstructure of the steels used in the study: (a) HSLA, (b) DP600, and (c) DP980, taken from [32].