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Yb:YAG laser welding of TRIP780 steel with dual phase and mild steels for use in tailor welded blanks

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ABSTRACT

Advanced high strength steels (AHSS) are essential to meet the demands of safety and fuel efficiency in vehicles. In this paper, we present the results of laser welding of two AHSS steels, TRIP780 and DP980. A 2 kW Trumpf TRUDISK 6002® Yb:YAG laser beam was utilized to join 1 mm thick TRIP780 with 1.5 mm thick DP980 and 1 mm thick mild steel. Optical metallography was used to characterize the weld profile and microstructures. Microhardness, tensile and fatigue tests were performed to evaluate the mechanical properties. Results indicate that the laser welds exhibit excellent strength and hardness with minimal defects which are attributed to the high beam quality, disk type of laser. In addition, there is a distinct effect of pre-straining of TRIP780 steels on the energy absorption.

1. Introduction

With the increases in energy consumption, the fuel prices have been steadily rising all over the world, resulting in higher demands for fuel-efficient vehicles. At the same time, due to increased awareness, consumers are looking for environmentally friendly vehicles that offer higher safety during crashes. As a result of these often conflicting demands, advanced high strength steels (AHSS) are aggressively deployed in automotive industry to reduce weight of the vehicle body and closures panels, while at the same time increasing energy absorption in some areas and stiffness in others. Considerable information on AHSS materials and their properties can be found in literature (for examples, see Refs. [1,2]).

Tailor welded blanks (TWB) is one method of making full utilization of AHSS. TWB's are blanks of differing materials and/or treatments, thicknesses, or surfaces, which are generally welded before the stamping operations are carried out. Since some AHSS steels such as transformation induced plasticity (TRIP) have high strength combined with improved ductility, it may be advantageous to use these steels where energy absorption and high strength characteristics are important, while other materials such as dual phase (DP) steels will need to be used where even higher strengths with reduced ductility are desired. Whether TWB's are used or not, attaching panels made of differing materials such as DP, TRIP and mild steel remains a challenge and a safe and reliable joining process is critical to the success of fuel-efficient vehicles.

In recent years, lasers are efficiently used to join different automobile panels. The lasers offer significant advantages such as high strength, excellent finish, simplicity, flexibility and reliability in manufacturing compared to other processes such as resistance spot welding, gas metal arc welding and electron beam welding. The chief limitation namely cost per watt is rapidly dropping with novel advances in laser technology. Autogenous welding is the most common form of laser welding although in some cases such as when a gap needs to be filled, a suitable filler material may be required.

Research has been carried out to understand the effects of laser welding on AHSS materials. Han et al. [3] butt-welded 800 MPa class TRIP steel using a CO_2 laser and found lower porosity at higher welding speeds. However, welding speed did not seem to have a perceptible effect on microhardness values. Gallagher et al. [4] used an Nd:YAG laser to weld HSLA300, DP600, M900 and M1310 steels at various speeds and found that weld tensile strength appeared to be dependent upon steel grade, weld penetration and weld width. However, weld fatigue strength was a function of material thickness rather than steel grade and microstructure. Others [5,6] have found factors such as weld concavity [5] and presence of zinc [6] to be significant in affecting the weld fatigue performance. Formability of the laser welds has also been investigated [7,8] with the ensuing conclusions that strength difference between the parent metals being joined [7] and soft zones formed in the HAZ [8] can be seriously influencing the formability of the joint. Finite element analysis using LS-Dyna software has also been successfully used on laser welding of DP980 steels to simulate the tensile test results for elongation [9] that allows easier prediction of the mechanical properties in the softened HAZ.

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New innovations being applied on other materials are also being researched for applications in the welding of AHSS materials. These include hybrid joining techniques such as Laser-MIG welding process [10,11], which can result in cost avoidance by eliminating edge preparation, typical of GMAW arc welding. Other factors such as the stability conditions for the hybrid laser-GMAW welding process [12] or the effect of the shielding gas on the stability of the hybrid Laser-MIG process [13] have not been researched for AHSS materials.

The microstructures obtained in the fusion zone of laser welded AHSS materials are mostly martensitic due to formation of austenite during the welding process and the subsequent high rates of cooling. This has been confirmed by Rizzi et al. [14] who conducted experiments on laser welding of TRIP, DP and martensitic steels. This may not hold true in all cases. For example, Xia et al. [15] used laser welding process on Al-alloyed TRIP steel with a chemical composition of Fe–1.5C–1.73Al–2Mn and found that ferrite was one of the predominant phases in the fusion zone due to the ferrite-stabilizing property of Al. In the HAZ of lower strength steels such as DP600, austenite formation will be higher at closer proximity to the fusion zone and the percentage of martensite in the HAZ decreases with increased distance away from the fusion zone. This has been verified by Yan and Gallagher [5] on DP590 materials. In the HAZ of higher strength materials such as M1310 steels, tempered martensite or ferrite could form resulting in softened regions [4]. When two materials of widely differing alloy compositions are laser welded, microstructures that emerge depend upon the composition of the fusion zone. This has been reported by Yan and Gallagher [5] who found formation of Widmanstatten Ferrite during welding of DP590 with EDDS (an Interstitial Free material).

A knowledge of the microstructure and mechanical performance of the fusion zone as well as heat affected zone (HAZ) obtained with laser welding is essential to ensure the reliability of the process. In this paper, laser welding of TRIP780 (galvanized) was investigated by autogenously welding it to DP980 (cold rolled) and to mild steel (cold rolled) separately using a high beam quality YAG laser. It was noted that during repair procedures, pre-strained TRIP780 steels might be re-used by welding them to other panels that are undamaged. In order to understand the performance of pre-formed TRIP780 steels, pre-strained strips of TRIP780 were also used in the experiments.

2. Experimental procedure

TRIP780 and mild steel were received in the form of large sheets of 1.0 mm thick, while DP steel was procured with a thickness of 1.5 mm. TRIP780 steel was cold rolled and coated with zinc using galvanized iron (GI) process. DP980 and mild steel were cold rolled without any surface protection. In contrast to DP steels, TRIP steels exhibit high work-hardening rates at higher strains. This work-hardening difference is one of the primary reasons for the enhanced formability of TRIP steels, a significant advantage over DP steels. Tables 1(a) and (b) lists the chemical composition and properties of these steels.

Strips of 75 mm width were cut from parent materials of TRIP780, DP980 and mild steel. Some of the TRIP780 strips were plastically deformed to 10% engineering strain (9.53% true strain) in an Instron Tester to study the effect of pre-straining on the performance of the joints. All samples were milled on the edges to ensure that the gap between the edges remained well within 10% (0.1 mm) recommended in literature for butt welding [5,7]. Since it is the most common form, butt joint configuration was used in all cases. A Trumpf high power TRUDISK® 6002 laser beam, delivered from a 6 kW Yb:YAG solid state laser (wavelength: 1030 nm, focal length: 200 mm, focal spot diameter: 0.6 mm) to a robotic arm via fiber optics, was used to weld the samples (Fig. 1a). The samples were held stationary in the fixture as shown in Fig. 1b, while the laser beam attached to the robot's end effector moved along the edges of the samples being joined. The laser beam was set perpendicular to the surfaces of the plates being joined. Bead-on-plate technique was initially used to determine the speed at which a laser power of 2 kW would achieve full weld penetration. Before the welding was carried out, the samples were cleaned in acetone to remove any debris and contamination remaining on the edges. After that, they were loaded on the flat surface of the fixture and clamped down while ensuring that the milled edges were firmly in contact against each other. The top plates and the bolts (two used on each side) assured that the plates being welded did not move during the welding operation. Locating scheme as shown in Fig. 1b assured consistency in the location of the samples, which minimized re-adjustment of the starting point of the laser beam and its direction of movement. Argon shielding gas was used at a flow rate of 30 l/min (1.8 cubic m/h) during the welding process, although in industrial practice, the shield gas may not always be used (for example, work carried out in Refs. [4,5] does not use shield gas). The direction of shielding gas flow was set perpendicular to the welding direction, with the nozzle moving synchronously with the laser beam to keep the shielding uniform over the weld pool. The welding was carried out at 2 kW at a constant speed of 70 mm/s (4.2 m/min) while ensuring that full weld penetration was achieved. The weld parameters and material combinations are shown in Table 2.

After the welding was completed, small samples were cut at a distance of 25 mm away from the edges to eliminate the effects of starting and stopping of the welding operations. They were then mounted in resin, polished and etched with 3% Nital solution for microstructural examination that included optical metallography and microhardness testing. All microhardness values were obtained in HV using a load of 0.3 kN.

Further, tensile test samples 10 mm wide at the grip and 6 mm in the mid region, as shown in Fig. 2, were prepared using high pressure hydro-jet cutting operation. Measurements of the cut samples showed that all samples were within 6.0 ± 0.25 mm. Statistical analysis showed that the standard deviation of the sample

Table 1b
Mechanical properties of TRIP780, DP980 and mild steel used.

Steel	Yield strength (MPa)	Ultimate strength (MPa)	Elongation (%)
DP980 CR	534	980	12.2
TRIP780 CR	471	792	18
Mild steel	215	355	37.8

Table 1a
Chemical compositions (wt%) of TRIP780, DP980 and mild steel used.

STEEL	C	Mn	Mo	P	S	Si	Cr	Al	B	Ti	V	Nb	Ni	Cu	N
DP980	0.135	2.1	0.35	–	–	0.05	0.15	0.45	0.007	–	–	–	–	–	–
7TCP780	0.19	1.58	–	0.013	0.025	1.6	0.07	0.036	–	0.027	–	0.038	0.02	0.02	
Mild steel	0.043	0.27	0.002	0.041	0.009	0.021	0.02	0.04	0.0001	0.002	0.001	–	–	–	0.0067