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Post weld-treatment of laser welded AHSS by application of quenching and partitioning technique

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ABSTRACT

Two-step quenching and partitioning (Q & P) treatment was applied on specimens of an advanced high strength steel (AHSS) after laser welding, for post welding treatment. In order to avoid formation of brittle martensite phase, which usually form due to very high cooling rate of laser welding. To simulate the effect of different Q & P parameters after welding in the most critical part of HAZ, several cycles were performed in Gleeble simulator and analyzed in advance. Subsequently some of the cycles were repeated after laser welding by using an induction heater close to the weld. Different techniques including SEM, EBSD and XRD were used to analyze the microconstituents of the structure and mechanical properties were investigated by micro-hardness measurements across the weld, tensile and impact toughness tests. The final structure consists of controlled amount of tempered martensite with precipitates, bainite laths and small amount of fresh martensite depending on the thermal cycles. In addition, samples heated at a temperature between Ms and Bs (in this case 540 °C) showed the best mechanical properties. Therefore, this technique not only improves the microstructure and mechanical properties of the fusion zone (FZ) and heat affected zone (HAZ) but gives also a quick industrial processing method for post welding treatments.

1. Introduction

The number of application in which advanced high strength steels (AHSS) are used, is growing due to their high toughness that can reduce the weight, fuel consumption and costs and last but not least, reduce the environmental impact. But processing of AHSS in which some kind of heat treatment is required to reach the desired mechanical properties, in order to be able to use them in different applications needs more caution [1].

One process method used by the industry is laser welding since it can increase the productivity, can be applied to variety of product geometries, thicknesses and materials without distortion; and it can reduce the weight of the component. There are two modes of laser welding, conduction limited welding and penetration keyhole welding. The resulting weld has wide heat affected zone (HAZ) in the former mode, while in the latter mode it acts as a line source of energy penetrating into the body of material producing narrower and deeper welds. The keyhole mode has higher power density than 10^6 (W/cm^2) which vaporizes the material and forms a cavity hole, which will be filled by the surrounded molten metal as the laser beam moves along the weld. The conduction mode show welding results in depth to width of about 3:1 compared to about 10:1 or higher for the keyhole mode. The cooling rate which is a function of the laser power and the interaction time between the beam and the substrate, is a key factor in defining the microstructure and mechanical properties of the welds [2]. The cooling rates estimated by different setting of laser welding parameters have been found to be much higher than the critical cooling rate for martensite formation. So, there is a risk of martensite transformation in the fusion zone (FZ) and HAZ [3]. In addition, grain growth in the HAZ can change the initial mechanical properties of the material. Thus, controlling the microstructure within the fusion zone and heat affected zone is a challenging topic that can be approached by different ways. Mostly, the idea is to control the micro-constituents by adjusting the welding parameters like speed or power of welding or by using different post-weld heat treatments [4].

Quenching and Partitioning (Q & P) is a heat treatment process in order to give fine grained microstructure by stabilizing the austenite in the steel. The whole procedure consists of three main parts, (i) fully or partially austenitization (ii) quenching the steel to a temperature between M_s and M_f to produce a specific volume fraction of martensite and subsequently (iii) heating to a temperature below or above the M_s temperature, partitioning temperature (PT), where the carbon can

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diffuse from martensite to austenite during the partitioning stage [4]. Therefore, the microstructure consists of retained austenite and martensite (also ferrite, bainite and precipitates depending of the CCT diagram of the steel) [5–7]. Presence of Si and Mn in the chemical composition of the steel is useful to suppress the cementite formation and slow down the kinetic of transformations. However, carbide precipitation and decomposition of austenite to bainite are not completely suppressed. So, during the partitioning step of the samples, there are a few phenomenon competing; i) carbon partitioning from preliminary martensite to austenite ii) carbide precipitation and iii) decomposition of austenite to bainite. Therefore, understanding the prevailed transformation at each condition has an important influence on predicting the final microstructure. The carbon concentration is one effective factor which makes austenite to stabilize at room temperature. Very fine austenite grain size, less than 5 µm, decreases the martensite start temperature significantly [8,9]. In addition, Lee et al. [10] reported that with decreasing austenite grain size, both B_s and B_f decreased and overall bainitic transformation rate was accelerated.

The Q & P process can produce not only complex fine grained microstructure but also give a higher transformation rate in different manufacturing processes [11,12]. By applying the Q & P processing concept to laser welding (see Fig. 1), the toughness of FZ and HAZ are expected to be preserved or even improved in comparison with the Base Metal (BM). Also, since the production speed is the most important parameter in industry, this method can significantly decrease the typical post-welding heat treatment times.

Different pre- and post-weld and Q & P treatments respectively of a spring steel containing 0.55% C and 1.64% Si, in austempered condition were investigated in order to avoid martensite formation in the FZ and HAZ. Results show that application of the quenching and partitioning (Q & P) process enables the control of hardness and a structure similar to the original carbide free bainite instead of martensite was achieved [13].

In the present study, Q & P process was implemented just after welding. The Q & P heat treatment starts with air cooling of the weld area to a temperature between M_s and M_f. The process is continued by isothermal holding at the same or higher temperature as quenching and the final step was quenching to room temperature. This technique is a promising method to produce a good combination of controlled amount of martensite from the first and final quenching that guarantee high strength. Since, this steel doesn't contain high levels of Si or Al in its structure, austenite stabilizing at low temperatures is very difficult. So, partitioning stage in this work is actually like the tempering stage for martensite formed in the first step, providing opportunity for phase transformation of retained austenite to bainite and precipitation of carbides, nitrides and carbonitrides in the steel.

The steel used in this study, is an Advanced High Strength Steel (AHSS) with low carbon and silicon contents. The effect of using a post weld heat-treatment similar to Q & P methodology after laser welding has been investigated from microstructural and mechanical strength point of view.

2. Experimental methods and materials

The chemical composition of the steel sheet, Domex 960 from SSAB, used in the present study is shown in Table 1. The typical application of this AHSS is advanced lifting devices and lighter transport solutions and components: The 5.5 mm-thick sheets were received in the thermo-mechanically rolled, annealed and grain refined condition with the yield strength of 960 MPa and elongation (A_5) of approximately 8% and had a microstructure consisting of ferrite and martensite. The transformation start temperature to martensite (Ms) is 440 °C.

Primarily, to see the effect of Q & P, 27 experiments simulating the weld in controlled conditions in Gleeble 1500, were performed at the Material Engineering Laboratory, Oulu University, Finland. The dimension of Gleeble specimens was 75 mm × 10 mm × 5.5 mm. As shown in Fig. 2, all Gleeble specimens were fully austenitized at 1350 °C for 2 s which is selected to simulate the coarse grain part of HAZ, with the highest probability to get martensitic structure. Then samples quenched with the cooling rate of 80 °C/s to (Ms-185 °C), (Ms-85 °C) or (Ms-20 °C) and isothermally hold at (Ms), (Ms + 100) or (Ms + 200) for 2, 5 or 50 s partitioning time before final quenching to room temperature.

Laser welding was conducted on the 200 mm × 100 mm sheets of 5.5 mm thickness. The sheets were prepared by cutting and after that machining to get flat surface for the laser welding. The keyhole penetration mode with the ytterbium Fiber Laser (YLR Laser-15000) was selected for the welding. Other welding parameters were adjusted to, 5 kW power, travel speed of 1.1 m/min, Argon was used as a shielding gas with flow rate of 20 l/min. The laser welded specimens were subjected to post-heat treatment directly after the laser welding with help of induction heater, placed above the specimen. The induction heating was steered by adjusting only the Voltage while the induction current was kept at max level. The thermocouple was spot welded 1.5 mm from the fusion zone (FZ) of the weld, and connected to data logger RS-232 to control the temperature during Q & P and to adjust the voltage in short time (less than 1 s). Different Q & P conditions of the investigated specimens are shown in Table 2. In addition, samples 16 and 17 are not post-weld heat-treated, and therefore denominated as "Ref. Weld".

2.1. Microstructural characterization

After grinding and polishing step by step until 0.05 µm, specimens were etched with 3% Nital for optical microscopy (OM) and scanning electron microscopy (SEM). The specimens were prepared for electron backscatter diffraction (EBSD) examination with a final polishing step of colloidal silica and after that were the samples electropolished by LectroPol-5, Struers, with A2 electrolyte at 30 V for 8 s. The analyses were done by orientation imaging microscopy (OIM) on a JSM-IT300 under the acceleration voltage of 20 kV; tilt angle 70; step size 200 nm. The orientation data were post-processed with the AZtech, oxford and Tango software. The same instrument was also used for Energy Dispersive Spectroscopy (EDS). Furthermore, volume fractions of retained austenite were determined by means of X-ray diffraction (XRD) analysis using a monochromatic Cu-Kα radiation at 40 kV and 45 mA. Diffractometer was used to scan the angular 2θ range of 35° to

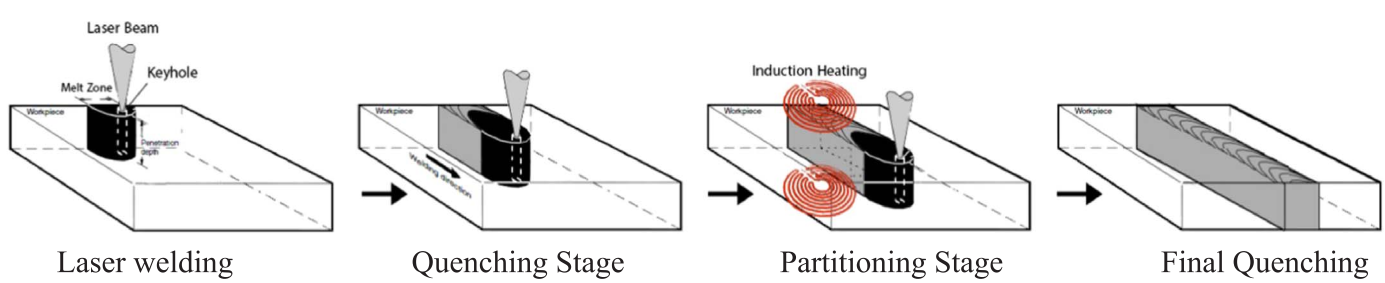

Fig. 1. Schematic of the keyhole fiber laser welding process with Q & P post weld heat treatment.