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Analysis of Laser Welds on Steel Processed by Q-P Process

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***Abstract*— The use of new advanced high-strength (AHSS) steels is often constrained by the state of the art in related processing and fabrication technologies. These technologies are only beginning to encounter the requirements that these advanced materials bring. Typical examples are joining and, in particular, welding. The latter has a major effect on microstructure evolution and, in turn, on mechanical properties. A common concern is that welding is not at all suitable as the joining technique for a particular application. This is why an experiment has been carried out which involves laser welding of a high-strength Q-P-processed AHS steel. Its results suggest that, by combining these technologies, very good results can be achieved, particularly in components under dynamic loading.**

***Keywords*— AHSS, Laser welding, Mechanical properties, Q-P.**

I. Introduction

Novel materials, including AHS steels, gradually put pressure on technologies used in processing and fabrication. These technologies include heat treatment and thermomechanical processing and joining techniques, including welding. The evolution of advanced steel processing technologies has led to strengths of about 2000 MPa and elongation levels of 10 % in steels with cost-effective alloying. This was thanks to the complex multi-phase microstructure of these steels. One of those microstructures is represented by the mixture of martensite and austenite and can be obtained by incomplete quenching and partitioning, known as the Q-P process [1]. The process is characterized by quenching from the austenite region to the region between martensite-start temperature (M_s) and martensite-finish temperature (M_f) [2,3]. There, just above the M_f, the cooling is interrupted. Consequently, martensitic transformation does not take place in the entire volume and some amount of austenite is retained [4]. This metastable austenite is typically found in the form of thin layers on the boundaries of martensite needles. However, it may also be present in other locations. Martensite imparts high strength to steel. Under normal conditions, however, it is too brittle and undesirable in parts intended for normal use and, in particular, parts operating under dynamic loading. This drawback can be eliminated by having an appropriate amount of austenite in the microstructure. Normally, the proportion is approximately 10 % but the amount of austenite may reach up to 20 %. Austenite has good plasticity. If distributed appropriately in the microstructure, it reduces the stress between martensite needles. Thanks to the plasticity of austenite, steel can be worked without suffering brittle failure, which is otherwise characteristic of martensite. For these reasons, metastable austenite must be retained upon cooling to ambient temperature and must not transform to martensite: this means it must be stabilized [5]. Saturation with carbon can provide this stabilization. Holding for several minutes at an elevated temperature causes a portion of the carbon atoms to diffuse from the martensite into the austenite. This stabilizes the austenite and relieves the stress in the martensite. A material with this microstructure exhibits excellent mechanical properties, including fatigue strength of more than 2000 MPa [6].

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II. Experimental

The objective of the present experiment was to explore whether Q-P-processed high-strength steels can be welded successfully. Specimens of 2.5-mm metal sheet of 42SiCr steel were butt-welded by means of laser [7]. The metallographic analysis and hardness measurement was performed across the weld (Fig. 1). The proportion of retained austenite in the matrix was 10%. To ensure that the test only reflects the effect of the welding process on the microstructural evolution and properties, the welded pieces were ground on both surfaces, so that stress concentrators were removed. The specimens had a gauge length of 5 mm and a cross-section of 1.2×2 mm. These specimens were used for tensile testing at various strain rates between 10^{-3} s^{-1} and 101 s^{-1}.

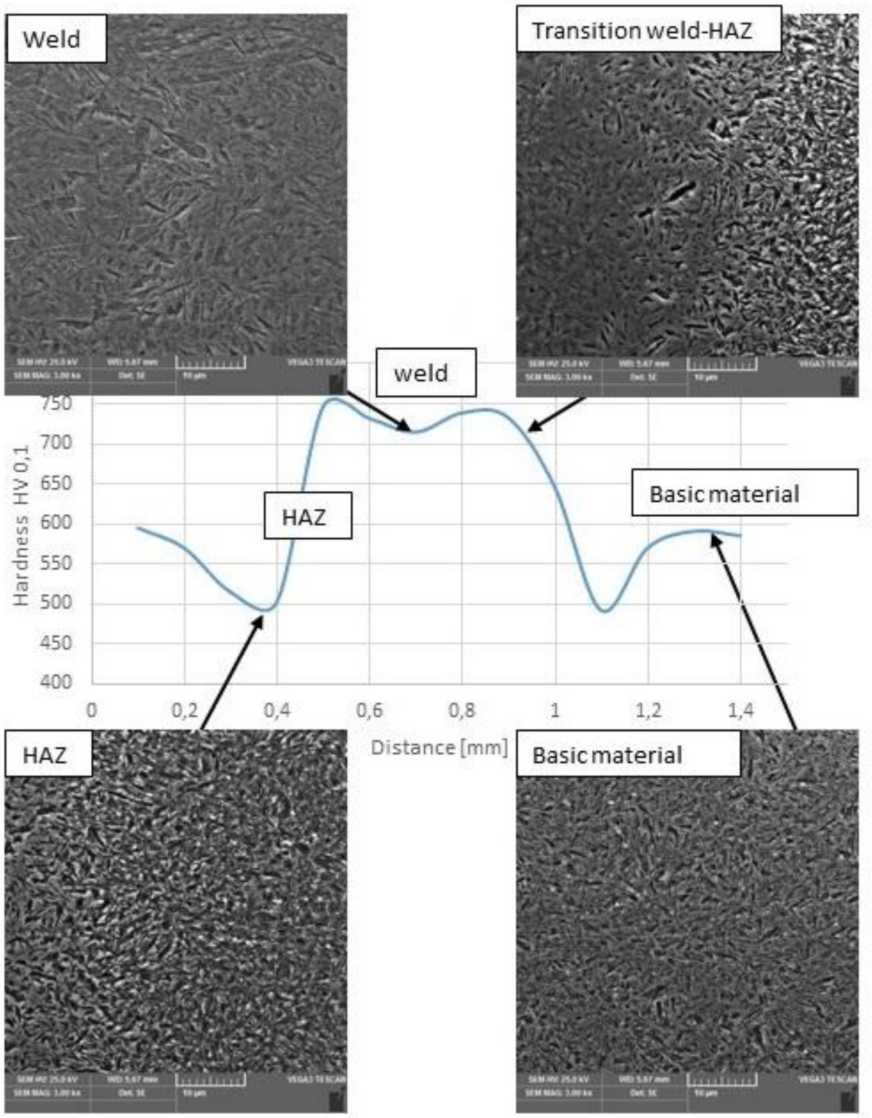

Figure 1 - The microstructures and hardness profile along the longitudinal axis of test specimen

III. Results

Microstructure had a martensitic character with stable retained austenite. Hardness profile range was from 500 to 750 HV0,1. Tensile testing showed that when a quasi-static load was applied, the failure occurred in the welded joint (Fig. 2). Despite this, the fracture was mostly ductile in nature. Only in some cases was there a minor proportion of brittle fracture (Fig. 3). A_{5mm} elongation value was

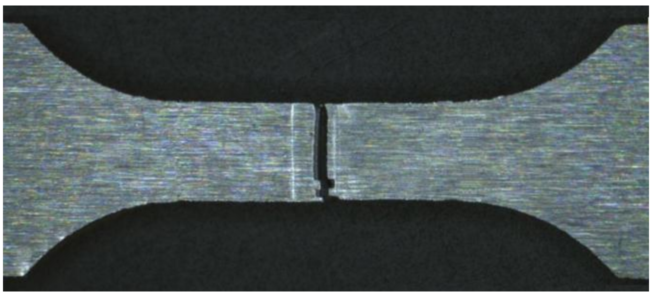

Figure 2 – Failure of welded joint under quasi-static load

Approximately 6 %. Ultimate strength was 1950 MPa (Fig. 4). When strain rate was increased by between 3 and 4

orders of magnitude, the type of fracture profoundly changed. In all tests, the failure occurred outside the weld and outside the heat-affected zone (Fig. 5). The base material underwent plastic deformation and the reduction of its cross-section was visible. The fracture surface was exclusively ductile (Fig. 6). Ultimate strength was comparable to the value found by the static test, approximately 1950 MPa. The ductility of the material, however, led to twice as high elongation level: approximately 12 %.

IV. Conclusion

The findings suggest that AHS steels can be welded using methods available today and that very good mechanical properties of welded joints can be achieved. In terms of the material per se, there is no obstacle to combining the Q-P process with laser welding in the processing of steels with 0.42 % carbon. Naturally, another logical prerequisite for success is an accurate definition of ranges of welding processing parameters, within which excellent results can be achieved, while keeping the process robust. To fully clarify these phenomena, further research is necessary. One can assume that the new findings will allow the welding process to be effectively optimized in order to achieve excellent results in laser welds of AHSS steels with strengths of about 2000 MPa.

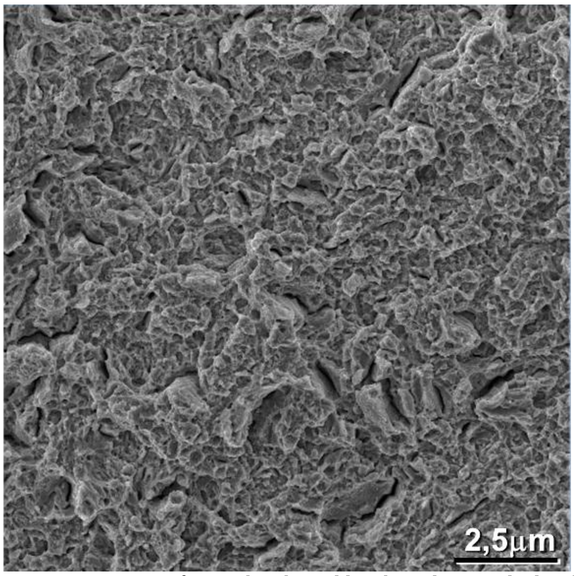

Figure 3 - Fracture surface within the weld with predominantly ductile fracture after a static tensile test

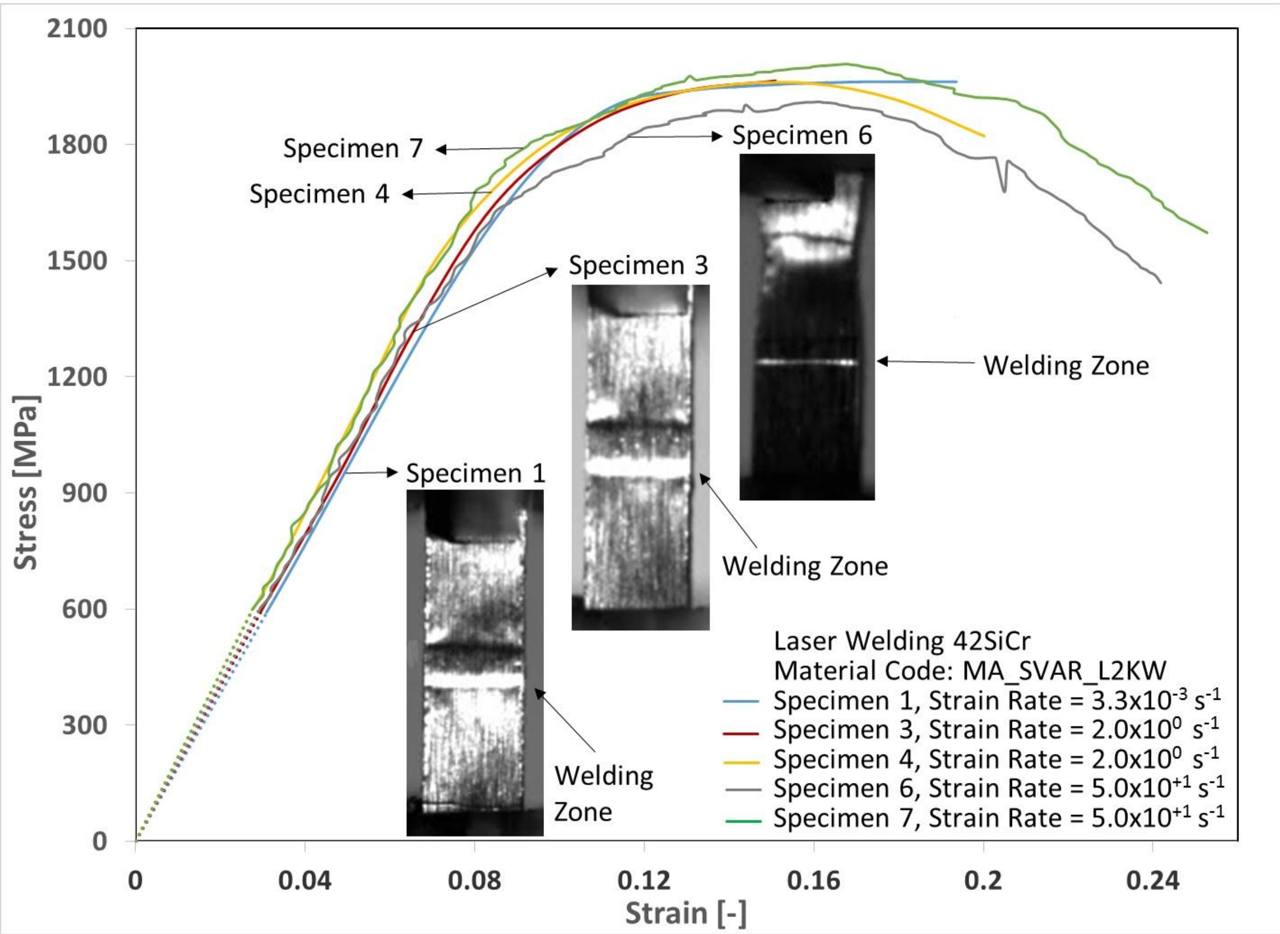

Figure 4 - Stress-strain curves for specimens with welds tested at various deformation rates

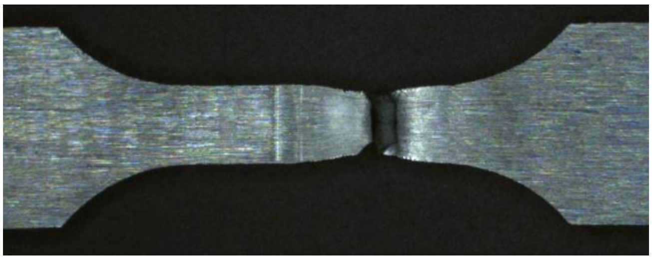

Figure 5 - Contraction of basic material outside the weld zone during the tensile test, position of the weld between the white lines

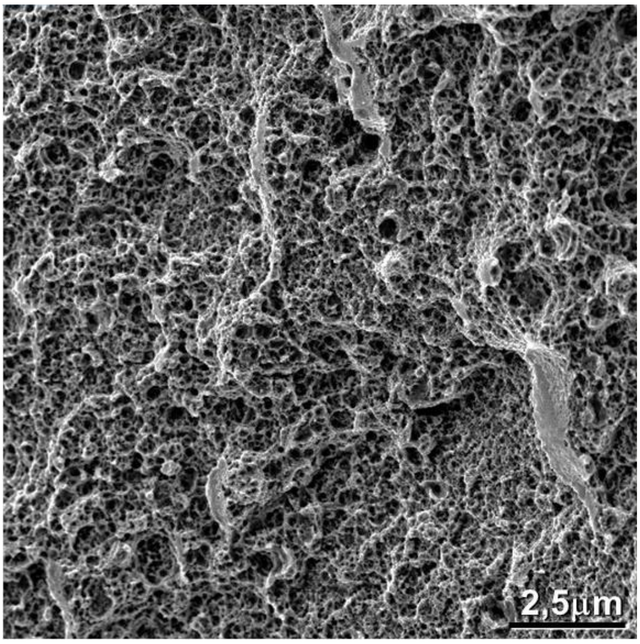

Figure 6 Fracture surface outside the weld and the heat - affected zone with ductile fracture after a dynamic tensile test

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About Author:

Ivan Vorel is the researcher focused on the development of high-strength steels and unconventional methods of production and processing of die forgings.