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Effect of Laser Shock Peening on the Microstructure of P265GH Steel and X6CrNiTi18-10 Stainless Steel Dissimilar Welds

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The aim of this study was to verify the laser shock peening (LSP) on the microstructure of P265GH steel and X6CrNiTi18-10 stainless steel. The LSP surface treatment was done underwater on the dis-similar weld joint of the P265GH and X6CrNiTi18-10 tubes. The metallographic analysis then focuses on the evaluation of microstructure in heat-affected zones of both materials. The results of our analysis are possibly summarised as follows. Light and scanning electron microscopy have shown grain refinement in the treated surface of the HAZ region of X6CrNiTi18-10 steel. For P265GH steel, it was possible to find a remelted surface layer with a thickness of 3.3±0.6 micrometers in the peened areas. For P265GH steel was also possible to observe a significant increase in deformation in the grains with straight contact with the peened surface by EBSD analysis. In the case of X6CrNiTi18-10 steel, this area extended to a depth of over 50 micrometers from the peened surface.

Keywords: LSP, Laser shock peeening, P265GH, X6CrNiTi18-8, Dissimilar welds

1 Introduction

Dissimilar (heterogeneous) welded connections are one of the critical areas in power systems where various ways are being investigated to ensure their longer service life and to reduce their operational wear. These weld connections can be found both in conventional coal-fired or water power plants and also in nuclear power plants, where they form, for example, the connection between austenitic piping systems and steam generator shell sleeves, which are usually made of ferritic-perlitic steel [1-2]. The critical area is, in this case, the area close to the weld root, which is in contact with the operating medium and where, due to the different mechanical properties and chemical composition of the materials used and heterogeneities in the heat-affected regions of the welded connection, ideal conditions for initiating its failure exist [1-4].

One of the technologies that are being considered for use to improve the service life of these critical areas of the dissimilar welded connections is LSP technology [4-7]. The principle of the technology is to generate compressive residual stresses in the surface layer of the material to be treated by means of laser pulses, thus increasing its fatigue life [8-10]. The change in the residual stresses is associated with plastic deformation of the material and microstructural changes that can be caused by plasma emerging during the interaction of the laser pulse with the treated surface [9].

In the case study presented here, an experiment we carried out to investigate and verify the possibility of applying LSP technology for the treatment of the inner side of critical areas of the dissimilar weld connection of the tubes made of P265GH steel and X6CrNiTi18-10 stainless steel which are used as pipelines materials in the manufacture of energy systems. Metallographic analysis by light microscopy, and scanning electron microscopy was selected to demonstrate the changes which should occur in these areas due to chosen LSP peening strategy.

2 Materials and methods

All samples for our experiment were made by single V groove welds of the two types of tubes done by TIG welding. The welded sample consisted of an P265GH steel tube on one side and an X6NiCrTi18-10 stainless steel tube on the other side. SV-07Ch25N13 austenitic steel welding rods were used as a filler material. The LSP process was done underwater condition in the water tank without ablative tape by a Bivoj SHG laser with a pulse energy of 0.2 J and beam size of 0.5 mm in the Hilase research center (FZU, Dolní Břežany, CZE). LSP treatment was done on the internal surface of the welded tubes up to the distance of 4 mm to both sides from the root of the weld, through heat affected zone to the area not affected by welding.

As stated in the study [11], the fact that the sample is treated in water without the use of ablative tape leads to surface reshaping and the formation of oxide layers on the peened surface. Ablative tape is used to limit the thermal load on the surface of the specimen to be peened [12]. The heat load is generated after the laser pulse impact on the surface structure of the sample, which is associated with the formation of plasma.Consequently, this could lead to its plastic micro deformation, but also to its local melting. After the melting of the surface layer due to its interaction with the plasma, there is also its interaction with the gaseous phase, which is formed because of the decomposition of the liquid by the emerging plasma [11]. At the point where the plasma acts on the treated surface, the expansion of the plasma also results in the displacement of the surrounding liquid and the formation of so-called cavitation bubbles, which, when they disappear, cause a second pressure shock that acts on the treated surface [13]. The authors of the present study [13] state that the pressure induced by the collapse of these bubbles decreases with increasing temperature of the water used and thus these secondary compressive stresses should be increased by reducing the working temperature of the used water.

Samples for metallographic observation were collected from 4 areas of welded tubes distant 90° among each of them. Discotom-10 metallographic saw (Struers GmbH, Roztoky u Prahy, CZE) was used to section each of them. Each sample for cross-section observation was then mounted by Citopress 30 hot metallographic press (Struers GmbH, Roztoky u Prahy, CZE) to PolyFast resin, and its surfaces were then grounded and mechanically polished by Tegramin-30 metallographic grinding machine (Struers GmbH, Roztoky u Prahy, CZE) using SiC papers grades 180-4000 and polished with diamond suspension 3-1 microns. Electrolytic polishing by LectroPol-5 (Struers GmbH, Roztoky u Prahy, CZE) using A3 electrolyte was then used. The microstructure of the samples was etched with a 3 % solution of Nital etchant and Carpenter etchant.

Metallographic analysis was then done by CarlZeiss Observer Z1m light microscope (Carl Zeiss s.r.o., Prague, CZ), and Tescan Mira 3 scanning electron microscope (TESCAN ORSAY HOLDING, a.s., Brno, CZE). All of the analyses were focused on the evaluation of the changes in both heat affect zones of the dissimilar welds caused by their LSP treatment. Microstructure changes were evaluated in the HAZ regions of the inner surface of the tube's dissimilar welds at the metallographic sample's cross-sections. The first one was close to the fusion line (FL), and the last one was approximately 4500 microns from this area. Change in the grain size in the HAZ regions caused by LSP was measured by the intersection method.

3 Result and discussion

The heat-affected zone of P265GH steel is quite heterogeneous place. The structure at the inner edge of the pipe at the boundary of the fusion zone of the weld root, its structure is formed by a ferritic structure, which gradually transitions into the ferritic-pearlitic region. In this subsequent region, the representation of structural phases, their morphology, and grain size gradually changes. Literature shows that ferritic structures processed by LSP technology have increased density of dislocations in the grains close proximity to the surface and the surface gets recessed surface [14]. In the literature [15] it is stated then that in perlitic structure there is a decrease in the proportion of lamellar cementite, which changes to granular cementite as a result of LSP treatment. In addition to the fragmentation of the cementite lamellae and their spheronization, the carbon released in the process diffuses into the ferrite crystal lattice [16]. The authors of this study also report that at the treated surface, if sufficiently high pulse energy is applied, the ferrite grain can be refined and the cementite lamellae can be completely spheroidised. The authors of the study [17] did an experiment with LSP treating ferritic-pearlitic medium carbon steel which was treated under water as our samples. They then observed approx 20 microns thin layer of martensite on the treated surface without change in the substrate below this layer. They concluded that the temperature in this place reached above A3 temperature so the structure is then transformed to austenite for a while and during self-quenching transformed to martensite structure [18].

From the opposite side of the dissimilar weld, its microstructure then consisted of an austenite structure. The austenitic structure can then undergo similar phenomena as the ferritic-pearlitic weld due to its processing by LSP. The authors of the study [19], for example, state that with increasing plastic deformation, dislocations within grains are rearranged and these then form dislocation walls or cells within austenitic grains. More dislocations then accumulate on these walls, which gradually transform these walls into new grain boundaries, i.e., local recrystallization of the material structure occurs. Another mechanism that may be involved in the grains refinement of the structure is dislocation-induced martensite as reported by the authors of the study [20]. As indicated in the [21] study, in order for the austenite to martensite transformation to occur, a sufficiently large compressive stress (5GPa<) must be introduced into the surface of the material to increase the density of dislocations in this region sufficiently to allow this transformation. t is also possible to observe an increased proportion of deformation twins in the surface layer as reported in reference [22]. All these described mechanisms of the material strengthening and microstructure transformations then cause an increase in compressive surface stresses, thereby increasing the hardness of the surface layer and increasing its resistance to external load and corrosion damage. Figure 1 below shows the macrostructure of the formed welded joint. In addition to this, the area in which the surface of the specimen was shot peened and the locations in which the microstructure analysis was carried out are marked on the image. From both heat-affected areas, a region within 2 mm of the fusion boundary was selected for closer metallographic analysis.

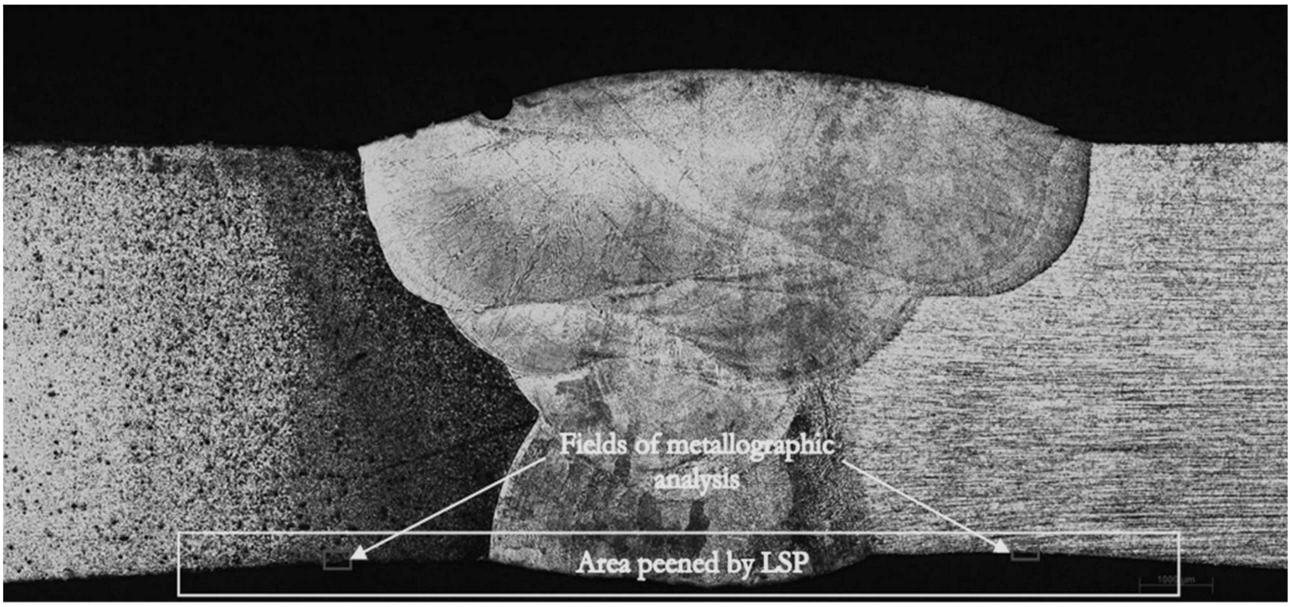

Fig. 1 *Macro etch of the evaluated dissimilar weld cross-section after LSP treatment. Left part of the weld consist of P265GH steel and right part of the weld consist of the X6CrNiTi18-10 steel. LSP treatment was done at the inner surface at a distance of 4 mm to both sides from the root of the weld*

Figure 2 shows a typical structure of the evaluated area recorded with a light microscope in bright-field mode. It can be seen from the images (2b) that the X6CrNiTi18-10 steel has a refinement of the grains structure at the surface to a distance of approximately 126±5 micrometers. The grain size in this area is around 23±5 micrometers. The ferritic-pearlitic region evaluated, see Figure (2a), has a finer ferritic grain structure compared to the austenitic structure. Its average value was around 10±2 micrometers. The refinement of this structure is not as apparent near the surface as in the austenitic structure, although it appears finer near the lower edge of the sample than at greater distances from this region.

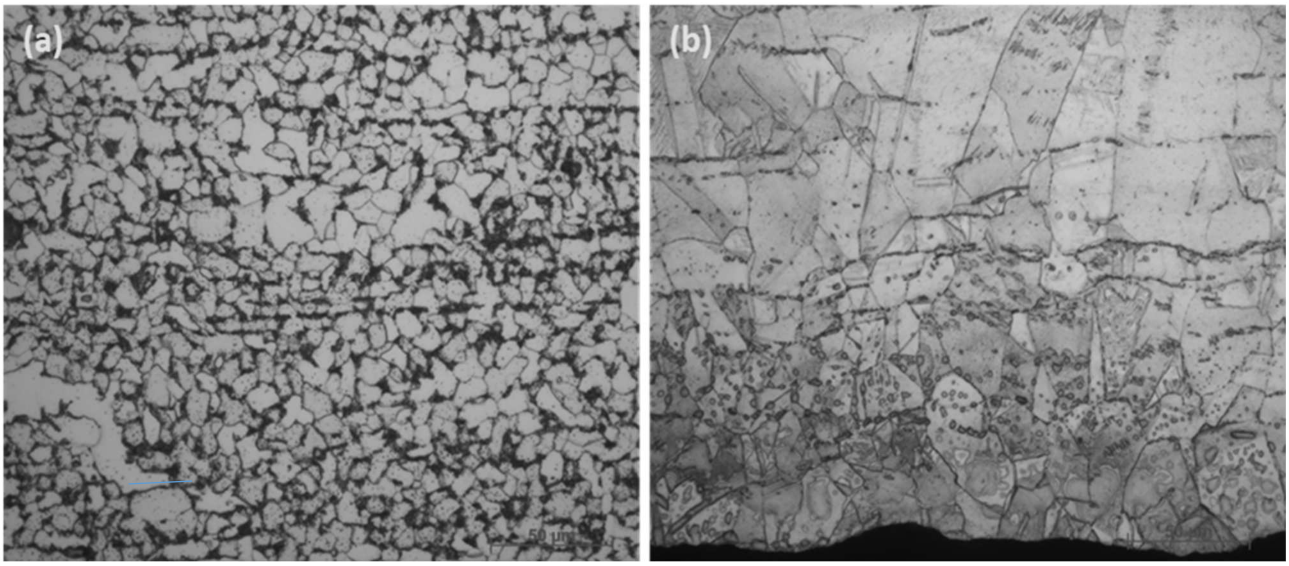

Fig. 2 *Microstructure of the heat-affected region at about 2 mm from the fusion boundary.(a) P265GH steel; (b) X6CrNiTi18-10 steel*

On the side of this steel, however, a thin layer with an approximate average thickness of 3.3±0.6 micrometers could be observed, see Figure 3. The figure also shows that in some of the perlitic colonies, the alignment of the cementite laths was disturbed. However, the effect is not significant.

Figure 4 then shows ipf maps of the analyzed areas from both sides of the dissimilar weld joint. The results show that the grain orientation is random in this region non affected by heat flow from the welding process and also show that the LSP process did not cause significant changes in grains orientation.

From the IPF map of the X6CrNiTi18-10 steel, it can be better seen that a thin layer with a very fine grain structure was formed on the surface of the sample, see Figure (4b). The thickness of this layer was not uniform and reached a depth of 15±7 micrometers. EBSD analysis was used to reconstruct the local misorientation, from which it is then possible to determine the density of dislocations in the analyzed areas. The results of this analysis are shown in Figure 5. From the presented results, it can be seen that in the surface layer of the austenitic steel X6CrNiTi18-10, there was a significant increase in the dislocation density of the material, i.e. there was a more pronounced plastic deformation compared to a similar region on the side of the ferritic-pearlitic steel P265GH. Also in the case of P265GH steel, it can be stated that there was an increase in the dislocation density at its surface, but only in the case of grains in direct contact with the surface. In grains further away from the surface, the increased dislocation density is probably associated with areas where lamellae or cementite particles were present which restricted the movement of dislocations and thus caused their accumulation to increase in density.

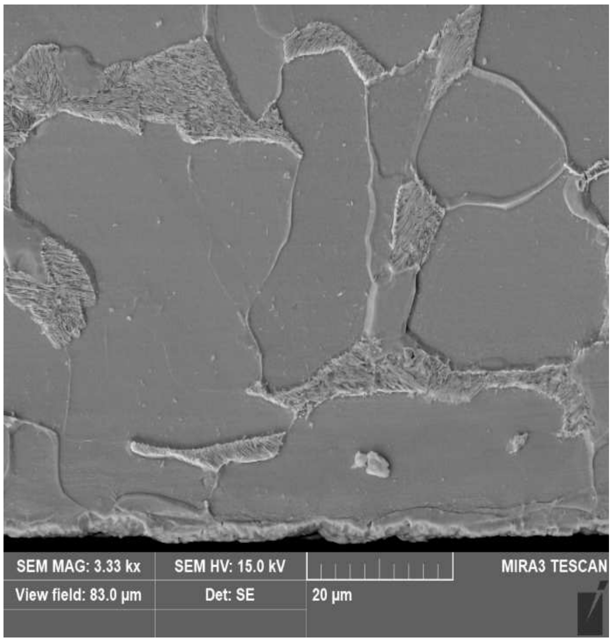

Fig. 3 *Detail of the surface remelted layer identified at the peened surface of the P265GH steel*

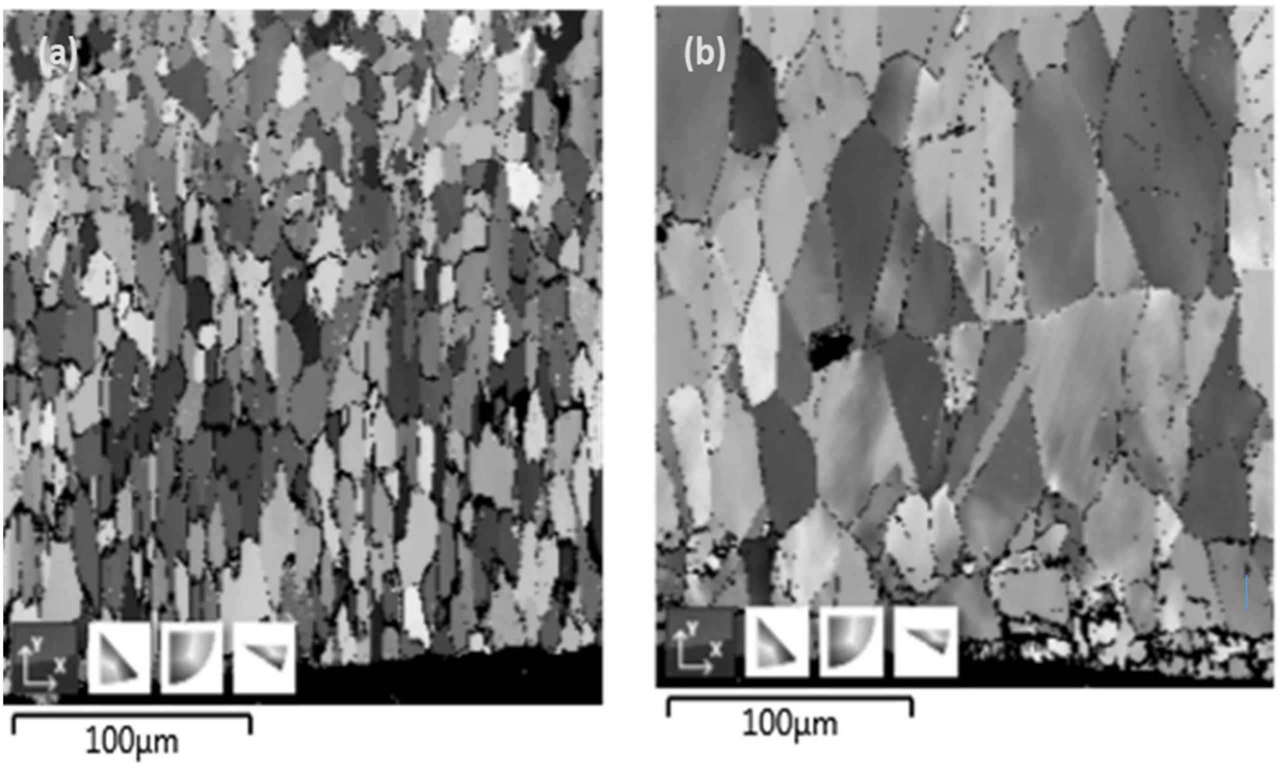

Fig. 4 *IPF maps of the heat-affected region at a distance of about 2 mm from the fusion boundary.(a) P265GH steel; (b) X6CrNiTi18-10 steel*

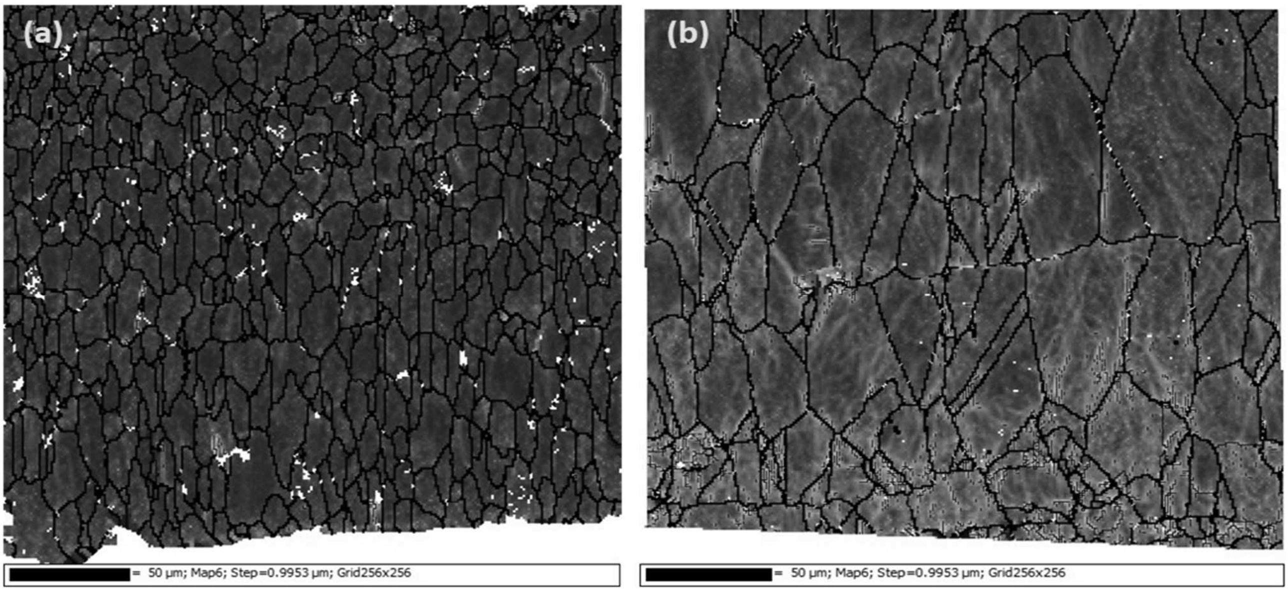

Fig. 5 *Local misorientation maps of the heat-affected region at a distance of about 2 mm from the fusion boundary.(a) P265GH steel; (b) X6CrNiTi18-10 steel*

The results show the positive effect of the LSP process especially on the refinement of the grain structure of the austenitic part of the welded joint. In its ferritic-perlitic part, its effect was not that significant. To increase this effect, it would be necessary, for example, to treat the surface using higher values of the laser beam pulse energy density.

4 Conclusion

The aim of our experiment was to verify the effect of the LSP process on the microstructure of selected regions of a dissimilar welded joint. The results of our experiment can be summarized as follows:

- The effect of LSP on the surface of the samples resulted in grain refinement of the material to a distance of 126±5 micrometers on the side of the X6CrNiTi18-10 steel.
- In the case of P265 steel, no significant change in the grain size of the material was observed.
- The formation of the remelted region was observed at the surface on the side of P265GH steel with a thickness of 3.3±0.6 micrometers due to LSP.
- Local misorientation maps showed that for P265GH steel there was a significant increase in deformation only in grains in direct contact with the surface.
- In the case of X6CrNiTi18-10 steel, the area of the higher deformation then extended over a distance of 50 micrometers.

In further planned experiments, a comprehensive evaluation of other areas of the LSP-treated weld joint will be carried out. The aim of our next analysis will be also to evaluate the mechanical properties and corrosion resistance will be evaluated in selected environments for LSP-peened samples and samples not LSP-peened.

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