Chapter12

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QUALITY INFLUENCE OF WELD SURFACE POST TREATMENT ON THE FATIGUE RESISTANCE OF WELD JOINTS

Abstract: This work deals with fatigue testing of the EN S355 structural steel weld joint. The weld was manufactured by the MIG welding technology and as the filler material was used the G3Si1 wire. The fatigue tests were carried out in the rotating bending mode on the specimens manufactured from the welded joint of the S355 steel. The main aim was to evaluate the fatigue endurance of the weld material and for this reason were used machined axis symmetrical specimens to remove the notch effect of the weld shape. In order to increase the fatigue endurance of the weld, the Nd-YAG laser was used for laser shock peening (LSP) of specimens surfaces, which lead to removing of the weld defects but in overall caused the laser bead on the smooth specimen has behaved as the notch and lead to decreasing of the fatigue endurance. Obtained results of fatigue tests are compared, discussed and supported by correlation with results of additional experiments, e.g. identification of incurred structures after the laser shock peening by the metallographic observations and micro-hardness tests.

Keywords: S355, weld joint, fatigue lifetime, laser shock peening.

12.1. Introduction

Welded joint is a local cross-section change and the place of highly inhomogeneous microstructure. It means that the weld is a place with high probability for the initiation and propagation of fatigue crack. For

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these reasons it necessary to know the weld fatigue behaviour to create a safer lighter and a more durable structures (MICHALEC I., MARÔNEK M., BÁRTA M., NOVÝ F., 2012), (MAZUR M., ULEWICZ R., BORKOWSKI S., 2012), (ULEWICZ R., MAZUR M., SZATANIAK P., 2012).

Weld itself contain several types of superficial defects and geometrical irregularities, especially cracks on the surface of weld or in the heat affected area, elevation of weld, undercuts in transitions to base material, defects in the root of weld and the internal defect such as pores, cold joints etc. All defects behave as the stress concentrators and led to the premature fatigue crack initiation which can significantly reduce the fatigue endurance of the welded joint. This work is not aiming on the shape irregularities but on the internal weld defects mentioned above and with options for their removal. Latest researches have shown enormous laser beam potential not only for cutting, welding, forming, surface heat treatments, etc. (MEŠKO J., ZRAK A., MULCZYK K., TOFIL S., 2014), but also for a marginal increase of the fatigue endurance, surface properties and corrosion behaviour of materials by using the shock wave of the laser beam (YOU L., LIQUN L., LINA S., 2015), (CHANG Y., YILIANG L., SUSLOVB S., DONG L., GARY J. C., 2014), (LIUCHENG Z., WEIFENG H., SIHAI L., CHANGBAI L., CHENG W., XIANGFAN N., GUANGYU H., XIAO JU S., YINGHONG L., 2016), (SHADANGI Y., CHATTOPADHYAY K., RAI S. B., SINGH V., 2015), (GANESH P., SUNDAR R., KUMAR H., KAUL R., RANGANATHAN K., HEDAOO P., RAGHAVENDRA G., ANAND KUMAR S., TIWARI P., NAGPURE D. C., BINDRA K. S., KUKREJA L. M., OAK S. M., 2014), (LAGO J., BOKŮVKA O., NOVÝ F., 2016). As the main advantage of the laser beam for the weld fatigue endurance is the remelting of the weld defects and incurring of the new, more durable microstructure as well as the ability to remove notch effect caused by these defects (LAGO J., BOKŮVKA O., NOVÝ F., 2016). For the identification of the incurred structures and evaluating the results, is important to gain the benefits of metallographic observations, where can be found a big advantage from other works based on the light microscopy observations and micro-hardness measuring.

12.2. Experimental work

Chemical composition of the EN S355 steel grade according to the EN 10025-2: 2005 standard is given in the Tab. 12. 1. and the mechanical properties in the Tab. 12. 2.

Table 12.1. Chemical composition of S355 steel (wt. %)

C % max	Si % max	Mn % max	P % max	S % max
0.23	0.05	1.6	0.05	0.05

Table 12.2. Mechanical properties of S355 steel

Yield strength Re [MPa] min	Tensile strength Rm [MPa] min - max	Elongation A5 [%] min
355	470 - 630	20

A copper coated G3Si1 solid wire for the MIG welding was used as the filler material. The chemical composition of the filler material can be seen in the Tab. 12. 3. The typical weld material mechanical properties are noted on the Tab. 12. 4.

Table 12.3. Chemical composition of G3Si filler material (wt. %)

C % max	Si % max	Mn % max	P % max	S % max
0.23	0.05	1.6	0.05	0.05

Table 12.4. Mechanical properties of G3Si weld metal

Yield strength Re [MPa] min	Tensile strength Rm [MPa] min - max	Elongation A5 [%] min
355	**470 - 630**	**20**

The welded joint was manufactured from the two identical sheet metal plates of 15 mm thickness. The weld areas were adjusted to the double V 60 degree bevel. The welding was carried out by the MAG welding technology. Weld joint has been sawn in the 15x15 mm square cross section pieces to ensure the optimal stocks for the turning. The specimens themselves were turned with the aiming for locate the weld in the middle of the specimens.

The experimental work was carried out on the rotating bending testing device. The loading frequency was chosen f = 35 Hz with the runout value at 2×10^7 cycles. For the LSP, the pulse Nd-YAG laser device with 1068 ηm wavelength was used with the Ar protective atmosphere directly supplied to the impact zone. The process parameters were 12 Hz pulse frequency, 16 ms pulse duration, 1.2 mm focus diameter and 20.3 J laser energy output. For process 80 % pulses overlapping in way of main feed and 20 % between each other laser beads were used to ensure enough surface homogeneity.

12.3. Results

The rotating bending tests has shown that the fatigue strength of welded S355 steel has decreased by the 14 % with respect to not-welded base material Fig. 12.1, where the base material reached fatigue limit of 290 MPa and welded only of 250 MPa. Obtained experimental data contain the big scatter caused by the randomly distributed admissible welds defects, mainly in the weld metal – base material interface area (fusion zone) and became the stress concentrators, what obviously led to the premature initiation of the fatigue crack. It’s the main reason why the welded material showed the overall decrease of the fatigue endurance. Laser shock peened (LSP) treated specimens showed even more decrease in the fatigue endurance, the test results were less scattered, however 21% lower when compared to the base material, respective fatigue limit of 230 MPa was obtained. It’s not clear why the LSP treatment caused this decrease and what caused the problem it not fully explained even by further analyses.

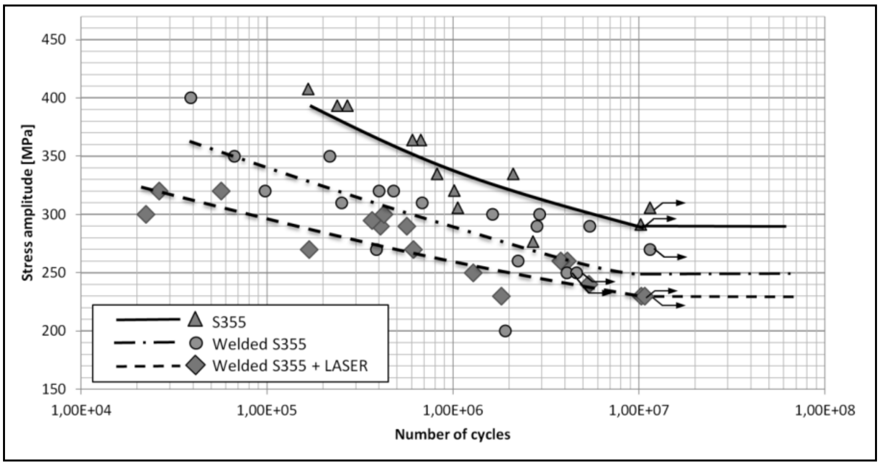

Fig. 12. 1. Fatigue lifetime of surface treated weld joints from S355 steel

Source: own research

Reduction of scattering in obtained results after the LSP can be explained by fracture surface observation (Fig. 12. 2 and Fig. 12. 3) and the position of the initiation point. Whereas for non-peened specimens the cracks were situated mainly in the weld metal and initiation points were the weld defects. In case of LSP specimens the initiations and cracks locations points were mainly on the specimen's surfaces, where the laser shock peening process has begun. Scatter reduction has become from the reason that the LSP has remelted the surface, removed the weld defects and focused the crack initiation on the place where the peening process on the smooth specimen has stared.

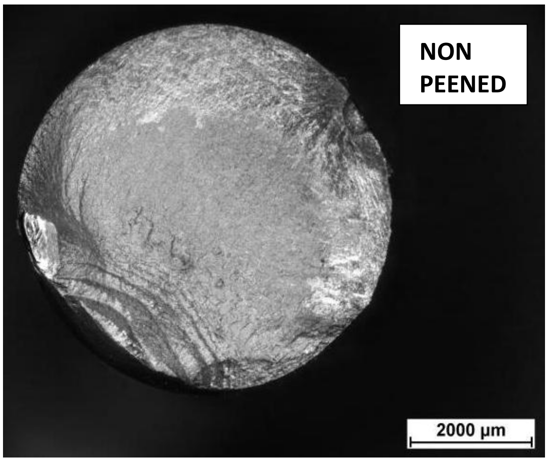

Fig. 12. 2. Fracture surface observation by stereomicroscope

Source: Own research

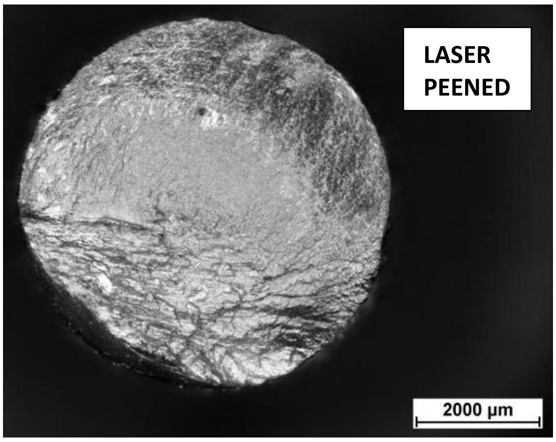

Fig. 12. 3. Fractre surface observation by stereomicroscope

Source: Own research

Given that it was necessary to carry out other tests, that would indicate the source of premature crack initiation, one of the backup specimen was cut in the middle longitudinal direction, as can be seen in the lower part of the Fig. 12.4. The surface was metalographically prepared and etched to reveal the microstructure. Results provided in Fig. 12.4 include welded joint macro, metallographic analysis of incurred structures and their hardness measurement in the longitudinal direction at three levels related to the distance from the original surface of the specimen. Macro observation showed no impermissible welded joints defects, problems in the laser shock peening process or geometrical problem that would cause the formation of crack initiation on the smooth specimen. Metallographic observations have shown the ferritic-pearlite fine grain rolled structure of the S355 steel without any non-permissible impurities or defects. In the Figures 12.5, 12.6 and 12.7 there are shown microstructures in the starting point, middle point and ending point of surface laser treatment. The weld contain fine ferritic-pearlite annealed structure incurred after annealing from heat input caused by the weld covering layers, which were machined out during the specimen manufacturing. Structure in the LSP inflected zone can be identified as the fine bainite which is also confirmed by the hardness results. The hardness states are represented by three curves on the different levels as was mentioned above. Measuring was carried out in the 0.1, 0.3 and in the 0.6 mm depths by the relative distance from the surface. In this point the only one explanation why the premature crack initiation has begun is the rapid increase of the hardness between the base material – LSP interface. This increase is 250 % from average 170 HV of base material, up to the 430 HV in the first laser shock peening bead, while other beads have been annealed by each other up to the last one, where the hardness reached the 382 HV because heat input from process increased the internal temperature of specimen and prevent as well amount of heat output for hardening as when the process has begun. Very low hardness declaim can be observed in the beginning and in the end of the process, where in the 0.3 mm depth hardness dropped approximately by the 20 HV.

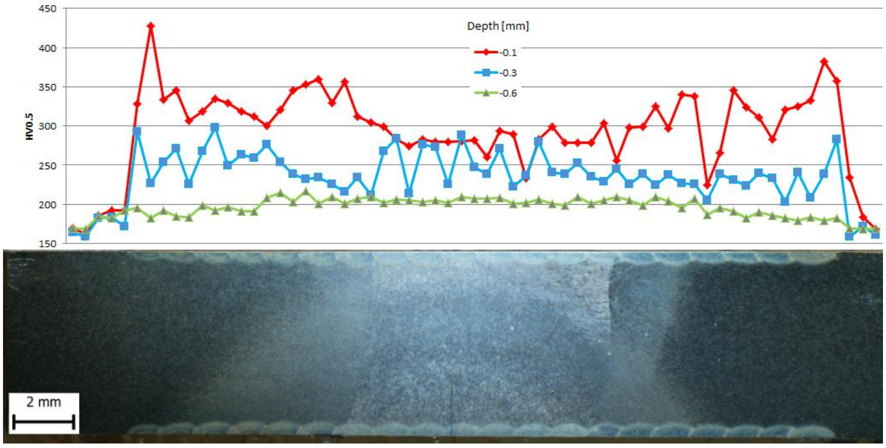

Fig. 12.4. Microhardness profile of the weld surface layer treated by laser

Source: own research

Fig. 12.5. Microstructure in the starting point of the laser surface treatment of the weld joint

Source: own research

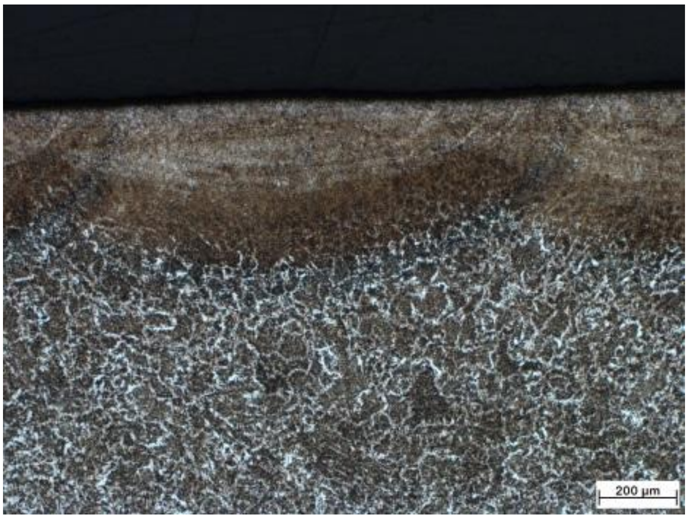

Fig. 12.6. Microstructure in the middle of the laser surface treated weld joint

Source: own research

Fig. 12.7. Microstructure in the ending point of the laser surface treatment of weld joint

Source: own research

12.4. Discussion

Present results of this work have failed to clearly identify the cause of decreased fatigue endurance of S355 welded joint after using LSP technology. Results of other works, where this technology was used for the similar purpose, concluded increasing fatigue characteristics, whether in carbon and stainless steels, aluminium and titanium alloys. However, the sudden hardness peak on to smooth specimen could cause the notch effect, better explanation for this problem would bring the residual stresses. In all works mentioned above the Nd-YAG laser was used for the LSP treatment, but with only one difference which is the pulse duration. Other works used pulse durations between the 20 to 100 ηs, while in this work was used the 16 ms pulse. This is the main breaking point because this duration is up to 800-times higher and can caused the lack of LSP shock wave energy to induce the compressive residual stresses. If the 16 ms duration has failed to create sufficient shock wave, it was impossible to obtain enough residual stresses or allow the tensile stress induction. For this theory confirmation it needs to be done further measure that will show the characteristics of residual stresses in the specimen after LSP process.

12.5 Conclusions

According to experimental work carried out on the welded S355 structural steel and treated by laser shock peening process can be concluded:

- fatigue strength of welded S355 steel has decreased by 14 % with respect to not-welded base material, where the base material reached fatigue limit of 290 MPa and welded only of 250 MPa.
- obtained experimental data contain big scatter caused by the randomly distributed admissible weld defects,

- LSP treated specimens showed even more decrease in the fatigue strength, the test results were less scattered, but the fatigue limit was 21 % lower when compared to the base material, respectively 230 MPa,
- LSP has remelted the surface, removed the weld defects and focused the crack initiation on the place where the peening process on the smooth specimen has stared,
- present results of this work have failed to clearly identify the cause of decreased fatigue strength of S355 welded joint after using LSP technology.

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