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Influence of High Frequency Impact Treatment (HiFIT) on fatigue strength of welded joints of high-strength steel S700MC for bridges applications

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Abstract. The paper deal with experimental fatigue test of arc welded joints of thermomechanicaly rolled structural steel S700MC, uses for heavy duty application like steel bridges structures. The aim of the work was to compare the fatigue strength of welded joints in two conditions, i.e. as-welded and after HiFIT process as a post-weld treatment and set the influence of HiFIT process on fatigue strength improvement. For this purpose three different welded joints have been prepared. The experimental test series were consist of butt welded joints, T-joints with longitudinal and transverse stiffeners. In the paper the fatigue characteristics S-N of welded joints have been presented as well as calculated fatigue category FAT. The study shows that the fatigue strength of welded joints of S700MC steel grade after HiFIT treatment is much more higher in each cases than the fatigue strength of non-treated welded joints. The obtained results can be used by engineers at the design stage or estimating the remaining fatigue life of the welded steel structure made of similar high-strength steel used for bridges application.

1. Introduction

Numerous investigations in recent years show that the fatigue strength of welded structures can be increased by different post weld processes that mainly rely on residual stress and weld geometry improvement methods. One of this method, which belongs to group of high-frequency mechanical impact methods (HFMI), is the High Frequency Impact Treatment (HiFIT) for post-weld fatigue strength improvement technique of existing and new welded steel structures exposed to variable loading conditions. The general idea of HFMI treatment is to employ alternate power sources, for example, ultrasonic piezoelectric elements, ultrasonic magnetostrictive elements or compressed air which accelerate cylindrical steel indenter or set of intenders against a component or structure with high frequency (>90 Hz). The impacted material is highly plastically deformed causing changes in the material microstructure and the local geometry as well as the residual stress state in the region of impact [1-4]. The area of application of the HiFIT includes steel bridges, load suspension means, cranes, wind power plans, building machines and many other steel structures [5].

In the literature there are many names to describe the devices used in HFMI treatment, for example ultrasonic impact treatment (UIT) [6], ultrasonic peening (UP) [7], ultrasonic peening treatment (UPT) [8] [9], high frequency impact treatment (HiFIT) [5], pneumatic impact treatment (PIT) [10] and ultrasonic needle peening (UNP) [11] [12]. In comparison to conventional hammer peening, the HFMI operation is considered to be more user-friendly and due to smaller spacing between alternate impacts the final surface is more smooth. While HFMI can be considered as environmental friendly, safe and relatively easy to apply, operators must still exercise safe work practice and understand the equipment and the nature of the post-weld operation which is being imparted to a welded structure.

2. Material and experimental procedure

2.1. Material

The material used in tests was thermo-mechanically rolled steel S700MC in the form of 10 mm thick plates. The chemical composition of S700MC steel is presented in table 1 and basic mechanical properties in table 2.

Table 1. Chemical composition of S700MC steel plate (acc. to certificate).

C %	Si %	Mn %	P %	S %	N %	Al %	Cu %	Cr %	Ni %	Mo %	Nb %
0,07	0,18	2,0	<0,012	0,001	0,005	0,049	0,03	0,06	0,16	0,12	0,08

Table 2. Mechanical properties of S700MC steel plate (acc. to certificate).

Yield stress $R_{e,}$ MPa	Tensile strength $R_{m,}$ MPa	Elongation $A_{5,}$ %	Impact energy KV_2 at -40°C, J
686	762	21	107

2.2. Test joints

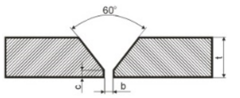
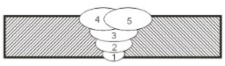
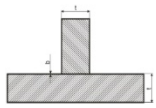
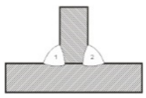
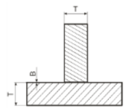
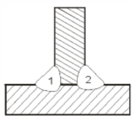
Welded joints were produced with 10mm-thick thermo-mechanically rolled steel S700MC. The test joints were produced by means of semi-automatic MAG welding method (135) with 1.2 mm-diameter solid filler wire BÖHLER X 70-IG and by use of KEMPPI ProMIG 500 welding machine. As a shielding the gas M21(82% Ar +18% CO_2) was used.

The test joints were made in three following configurations:

- Butt welded joins with full penetration,
- T-joints with double-sided fillet welds,
- T-joints with longitudinal rib with fillet and peripheral fillet weld.

The details of welding parameters are summarized in table 3.

Table 3. Technological parameters of welding process.

Type of joint	Butt joint	T-joint with double sided fillet weld	T-joint with longitudinal rib and peripherial fillet weld
Joint design and welding sequences	 t = 10 mm; b = 2 - 3 mm; c = 1 – 2 mm 	 t = 10 mm; b = 0 - 1 mm 	 t = 10 mm; b = 0-1 mm 
Welding method:	135	135	135
Size of filler material:	Ø1,2 mm	Ø1,2 mm	Ø1,2 mm
Current:	112-121 A (run 1) 240-254 A (runs 2-5)	230-244 A	248 A
Voltage:	16 V (run 1) 26 V (runs 2-5)	26-26,5 V	26,8 V
Travel speed:	138 mm/min (runs1) 350 mm/ min (runs 2-3) 400 mm/min (runs 4-5)	380 mm/min	380 mm/min
Wire feed speed:	6,5 m/min	6,5 m/min	6,5 m/min

2.3. HiFIT process of test joints

Proper impact machining (hammering) using the HiFIT method requires the selection of appropriate parameters of this process. The selection of such parameters was carried out in an experimental manner, in accordance with the device operating instructions.

The relevant parameters are selected by setting the correct working pressure, selection of the intensity of hammering by turning the screw causing the piston stroke to change and proper pin angle to obtain a smooth surface without burrs in the work area and to get the processing depth within 0.2-0.35 mm.

The HiFIT was carried out at the station equipped with HiFIT device with standard pin with a tip diameter D=3 mm, flexible air joint and air filter with pressure gauge to adjust the supply pressure The test joints to be treated were fixed to the table using conventional joinery clamps (Fig. 1) and the HiFIT process was carried out according to parameters as presented in table 4.

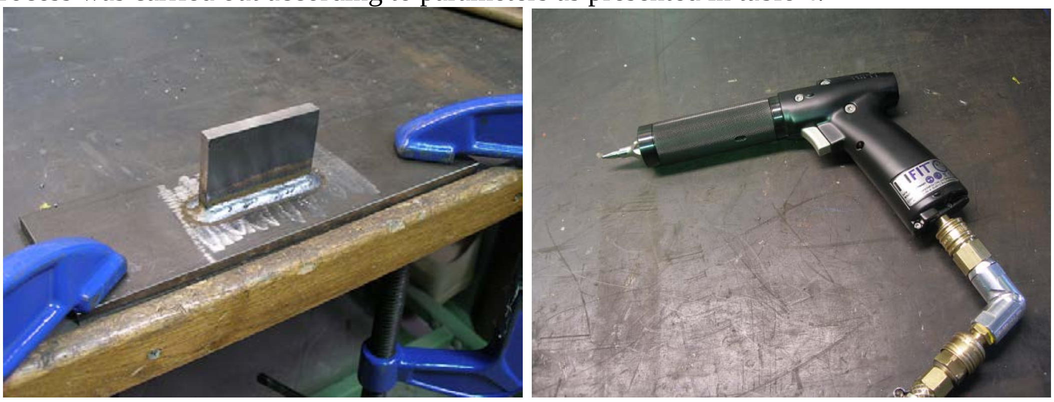


Figure 1. Example of test joint clamping (on the left) and general view of HiFIT system device (on the right).

Table 4. HiFIT process parameters.

Working pressure (bar)	Impact intensity	Pin movement speed, (mm/s)	Pin angle against treated surface (°)	Pin angle against movement direction (°)
4,8-5,0	Small (high frequency)	3,0-5,0	60-80	70-90

2.4. Experimental fatigue test procedure

Fatigue tests of three type of welded joints in “as welded” and after HiFIT treatment conditions were conducted with testing machine MTS 810. Fatigue tests of each lot of samples were performed for several ranges of stresses $\Delta\sigma$ with stress ratio R=0.2 ($R=\sigma_{min}/\sigma_{max}$) and changing load frequency of 20 Hz until reaching the moment of the test sample failure. The number of samples in each lot amounted to 10, which enabled the determination of S-N curves and calculation of fatigue category FAT pursuant to the guidelines of the International Institute of Welding (IIW) [13].

3. Results and discussion

The goal of these investigation was to verify whether the HiFIT can be used for effective fatigue life improvement of most popular types of welded joints made of S700MC steel grade and to estimate the efficiency of this modification. The main work was focused on experimental fatigue test (axial tension) of the joints performed in two different conditions, i.e. as welded and after HiFIT process. The test results as a fatigue curves are presented in figures 2-4. The blue lines represents S-N curves while the red triangle represents fatigue lives of each tested specimens. In table 5 the list of calculated FAT classes and HiFIT process efficiency for each type of joints are presented.

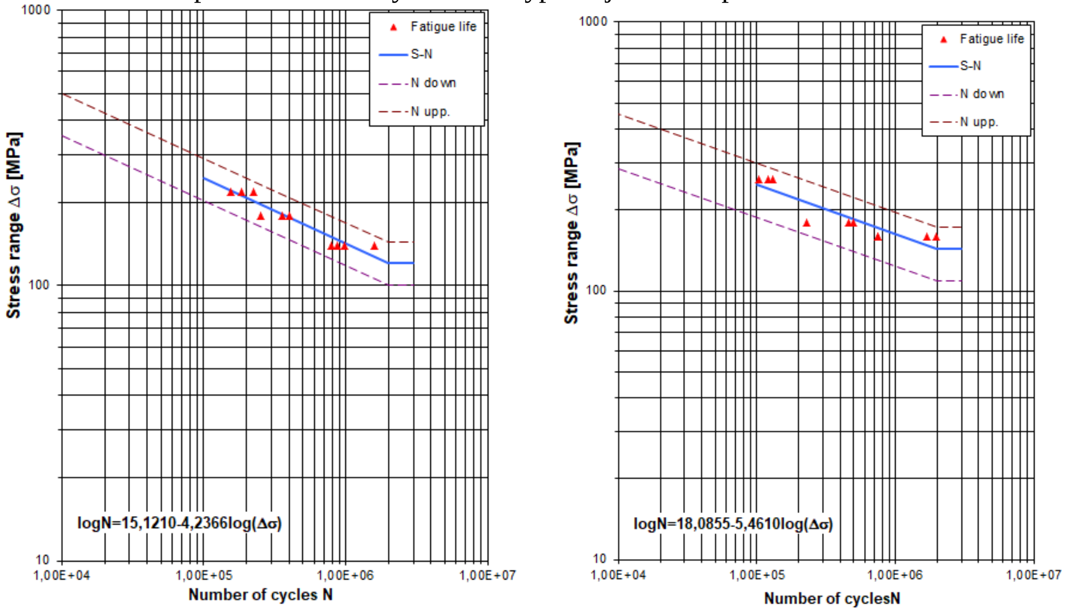


Figure 2. S-N curve of butt welded joints;
a) in “as welded” condition, b) after HiFIT process.

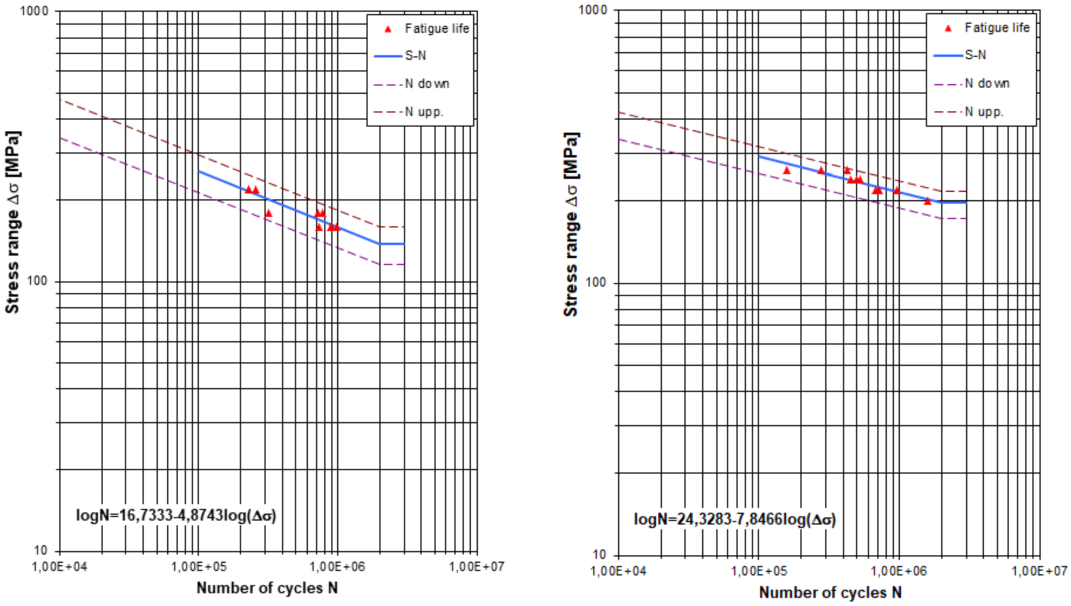


Figure 3. S-N curve of T-joints with double fillet welds;
a) in “as welded” condition, b) after HiFIT process.

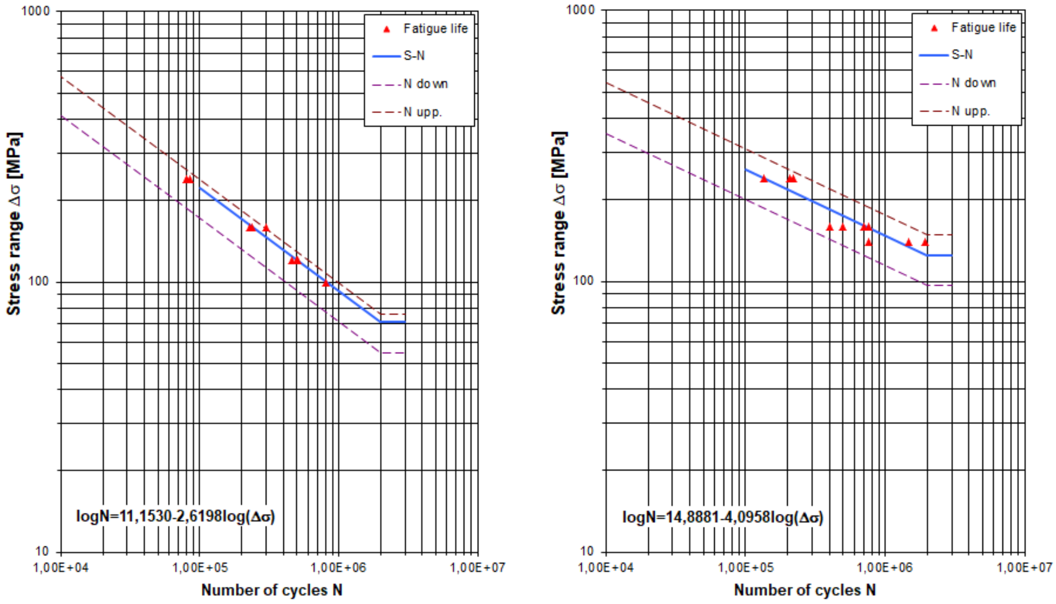
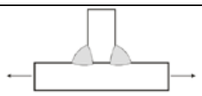
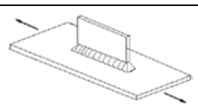


Figure 4. S-N curve of T-joints with longitudinal rib and peripheral fillet weld;
a) in condition "as welded", b) after HiFIT process

Table 5. Comparison of FAT classes for welded joints with and without HiFIT process

Type of joint	Joint sketch	Fatigue class FAT, MPa: As welded	Fatigue class FAT, MPa: After HiFIT	HiFIT efficiency, %
Butt joint		72	85	**18%**
T-joint		98	159	**62%**
T-joint with longitudinal rib		30	71	**137%**

Analyzing the results, it can be seen that in every type of welded joints of S700MC steel, the use of HiFIT process resulted in the increase of fatigue strength. For butt welded joints the increase in fatigue strength expressed in the FAT class was 18%, which is the smallest increase among the tested joints in this work. In the case of T-joints with double-sided fillet welds, the benefits of HiFIT reach a 62% increase by comparing fatigue categories of joints before and after HiFIT process. The highest increase in fatigue strength after the application of HiFIT process was obtained for joints with an longitudinal rib with a circumferential fillet weld, for which the fatigue category of FAT is higher by as much as 137% in comparison to fatigue category FAT joints in "as welded" condition.

The test results confirm the principle that if the notch is bigger (the more significant its effect), the increase in fatigue strength due to the HiFIT impact treatment is also bigger. Regarding the subject of the research, the biggest notch was the longitudinal rib, and for these joints the effect of HiFIT process is the highest, while the mildest notches are undoubtedly the reinforce of face and root in butt welds, therefore the impact of HiFIT process on fatigue strength increase is also lower.

In conclusion, and referring to the purpose of the work, it should be stated that the application of HiFIT process for welded joints of S700MC steel is justified in order to increase the fatigue strength of welded steel structures. Obtained results of research can be an unquestionable argument for the environment of both designers and manufacturers of steel structures of high strength steel, which are designed taking into account their exposure to fatigue.

4. Conclusions

Based on the conducted tests and the analysis of results, the following conclusions are drawn:

1. It is possible to modify the fatigue strength of welded joints of S700MC thermomechanical steel by means of local impact machining of welds using HiFIT process.
2. The degree of increasing the fatigue strength of FAT after applying HiFIT process for a selected steel grade depends on the type of joint and is connected with the sharpness of the notch of a given welded joint.
3. The increase in fatigue strength of S700MC welded joints after the HiFIT process is 18% for butt joints, 62% for T-joints with double-sided fillet welds and 137% for T-joints with longitudinal rib and peripheral fillet weld.
4. HiFIT device for impact treatment of joints is easy to use and offers the possibility of conducting an efficient process of modification of fatigue strength of welded joints.

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