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THE INFLUENCE OF THE BUTT WELD ON FATIGUE LIFE

Stanisław MROZIŃSKI[1], Jarosław PEPLIŃSKI[2]

[1,2] *University of Technology and Life Sciences in Bydgoszcz, Faculty of Mechanical Engineering, Al. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, tel.: 48 52 340-82-64, fax: 48 52 340-82-71, e-mail: mrozinski.stanislaw@utp.edu.pl*

Abstract

In the paper there were presented tests results which were aimed at determination of the influence of the butt welds on fatigue life. Basing on the comparative analysis of the fatigue tests results of welded joints and specimens without butt welds it was found that fatigue life of the welded joint undergoing the mechanical working is comparable with the fatigue life of the homogeneous material. The Locati method used during the tests allows for the approximate determination of the fatigue limit.

***Keywords**: welded joints, fatigue life of construction elements*

1. Introduction

The idea of construction element is inseparably associated with existence of various types of notches formed for designing reasons or occuring as a result of various technological operations including welding process. Because of that, joints are natural locations of fatigue cracks initiation which, when developing, may lead to serious failures or catastrophes [1].

Research work presented in this paper is a part of a research program carried out in the framework of doctoral dissertation. Its main aim is the fatigue life improvement of welded elements. In this work there were presented preliminary tests results, which aim to determine the influence of butt weld on static strength and fatigue life of welded joints.

2. Description of tests

Specimens used in the tests were made of 355J2+M steel according to standards [2] and [3]. They were cut out from two 180E channel irons joined with butt weld. The location on channel iron from where the specimens were cut out is shown in Fig. 1.

After specimens have been cut out they were subjected to mechanical treatment (milling and grinding). In order to define the influence of butt weld on static strength and fatigue life, specimens made of homogeneous material were also prepared (Fig. 1 – specimens without welds). Specimens without welds were given the same mechanical treatment as the samples with welds. Before fatigue and static tests the specimens with welds underwent the non-destructive tests.

Static tests were performed according to the standard [2]. They were performed on Instron 8501 strength machine. Specimens strains during static tests were measured with the use of extensometer of gauge length – 50 mm.

Because few specimens were accepted in the tests (3 specimens) and because of practical aim of the tests (quantitative valuation of the welds influence on fatigue life) they were performed with the use of preliminary Locati method [4, 5, 6].

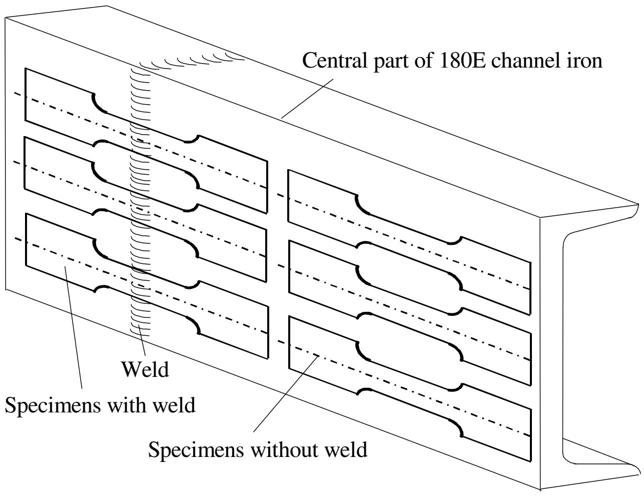


Fig 1. The location of specimens on channel iron

Locati method can be used when approximate data describing fatigue properties of given group of elements are already known, for example shafts, cog wheels, in the form of fatigue diagram equation described with the equation:

$$\log \sigma_a = a \cdot \log N + b \tag{1}$$

In Locati method a specimen is under gradually increasing loading (Fig. 2a).

a) b)

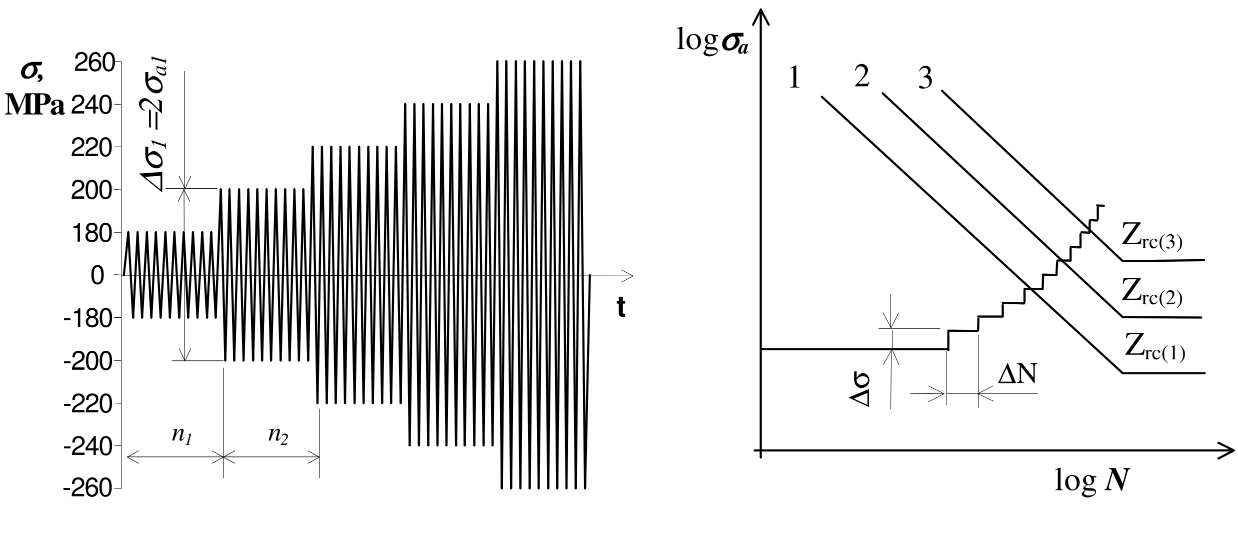


Fig 2. Model to define fatigue limit with the use of Locati method: a) loading program, b) interpretation of results

On each step the same number of loading cycles n_i is performed (in this test n_i =10^5 cycles). The stress increase $\Delta\sigma$ depends on test conditions and volume of loading (in this test $\Delta\sigma$=20 MPa). The stress level on the first step (σ_{a1}) should be lower than determined fatigue limit $Z_{rc(2)}$ (in this test σ_{a1}=180 MPa). Final loading, however, for which the failure of the element takes place, should be higher than upper fatigue limit $Z_{rc(3)}$. Loading frequency accepted during the test was equal 5 Hz. In fatigue limit calculations with the help of Locati method the Palmgren-Miner fatigue damage cumulation hypothesis is used [7, 8]. According to this hypothesis fatigue failure appears when:

$$\sum \frac{n_i}{N_i} = 1 \tag{2}$$

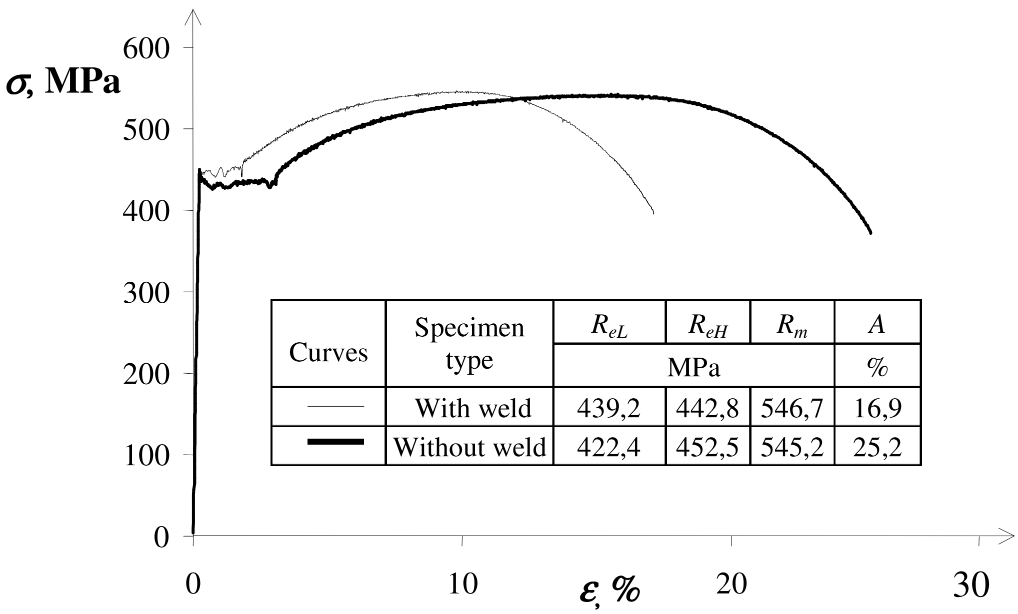
where:
n_i – number of loading cycles on stress level σ_{ai},
N_i– number of loading cycles until fatigue failure on stress level σ_{ai}.

In Fig. 2b there was presented graphical interpretation of Locati method. Fatigue curves 1, 2 i 3 (Fig. 2b) limit the area of dispersion of fatigue tests results from the bottom and top. This dispersion is most often unknown, so the curves, in such a case, will have approximated courses. The damage cumulations $\Sigma n_i/N_i$ are calculated after tests with the use of individual fatigue curves and performed loading programs. Mostly, none of the sums $\Sigma n_i/N_i$ equals 1,0. So for final determination of fatigue limit an auxiliary curve is produced for the interpolated determination of fatigue limit. Detailed description of Locati method can be found among others in the work [4].

3. Test results

3.1. Static tensile tests

The results sample of static tests are shown in Fig. 3 (curves of static tensile).



Curves	Specimen type	R_{eL}	R_{eH}	R_m	A
		MPa			%
	With weld	439,2	442,8	546,7	16,9
	Without weld	422,4	452,5	545,2	25,2

Fig . 3. The results of static tensile tests

As it was expected, during static tests no significant influence of butt weld on strength was observed (Fig. 3). On the basis of comparative analysis of strength parameters it can be stated that influence of weld is visible only as decreasing of the total elongation of the specimen until failure (A). Specimens with welds are characterised by smaller elongation (about 32%). In the case of the other parameters (R_m, R_{eH}, R_{eL}) weld had no significant impact on the results.

The cracking of all the examined specimens took place within the gauge length of extensometer. As it was expected the cracking of the specimen with weld occurred always outside the welded area (Fig. 3). Detailed examination of the cracks did not show any defects or interferences. The shapes of damages of examined specimens are shown in Fig. 4 and 5.

Fig. 4. Shape of damage of specimen without welds

Fig. 5. Shape of damage of specimen with weld

3.2. Fatigue tests

Fatigue cracks of the specimens without welds occurred in the measuring area or in the place where measuring area turns into grappling area. Fatigue cracks of the specimens with welds occurred in the area of thermal influence or in the place where measuring area turns into grappling area. The location of cracks in specimens with welds (outside the welded area) is the proof of very high quality of welds. The shapes of cracks in both types of specimens are shown in Fig. 6.

Basing on the comparative analysis of the cracks which occurred in specimens with and without welds it can be stated that welds had no influence on the shape of damages. The above statement was proved by the results of comparative analysis of cyclic properties and fatigue life of the two types of specimens.

a)

b)

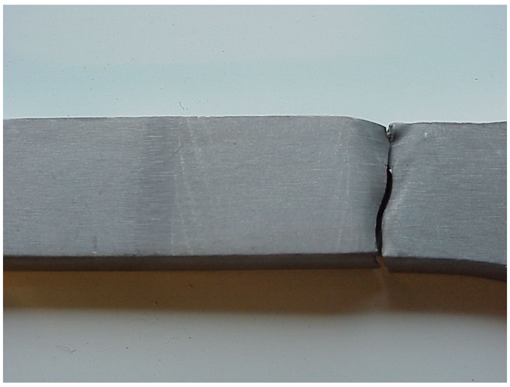


Fig 6. Shape of cracks in specimens with welds in the measuring part of the specimen

During analysis of the fatigue tests results, there were used momentary force and strain values of the specimen recorded for chosen loading cycles on succeeding levels of loading program. (Fig. 2a). In Fig. 7 there are shown an examples of one hysteresis loop which corresponds with the first loading cycle for each step of loading program.

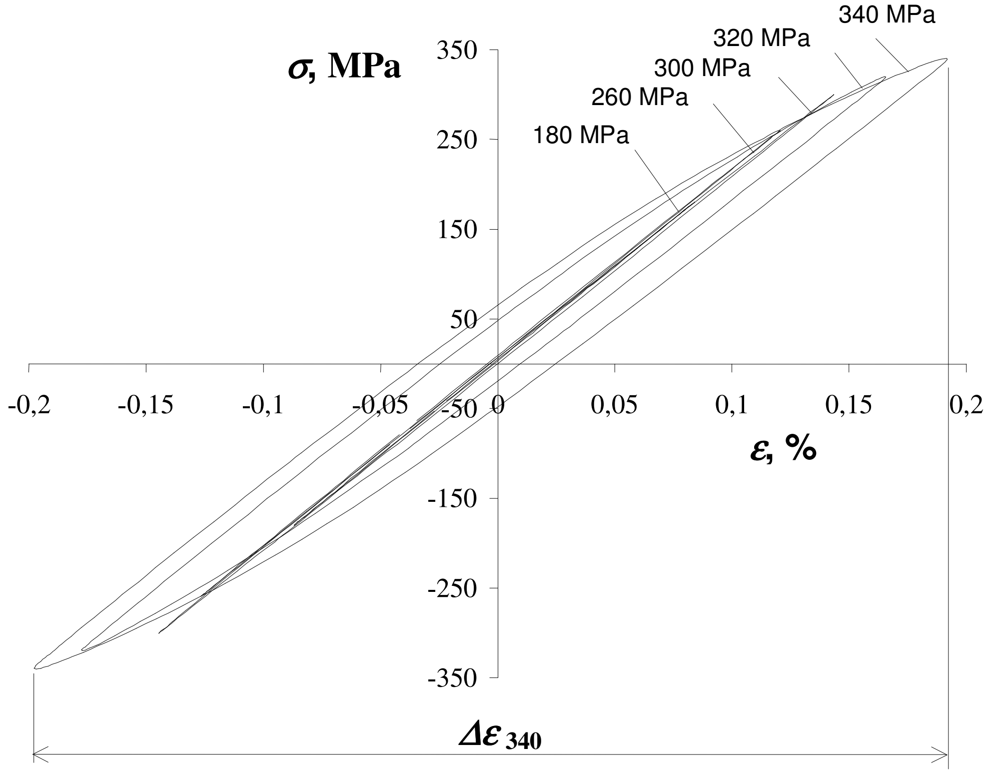


Fig. 7. Hysteresis loops recorded during tests (specimens without welds)

Basing on the analysis of the presented diagrams it can be stated that for the last three levels of stress (σ_a=300, 320 and 340 MPa) in the result of oscillatory loading there occurs stress - strain loop, which proves the presence of plastic strains on these stress levels. The above was observed both in samples with and without welds. On the basis of recorded loops it can be stated that although the level of stress was controlled, (σ_a=const) strain symmetry occurs on respective steps of loading program. Average strain values close to zero can be the proof of this. What is more, in spite of the stress controlling, no cyclic creeping of the material, which is often observed in such conditions, was observed.

In this paper there was carried out the comparative analysis of cyclic properties of the specimens with and without welds. During analysis the parameter of hysteresis loop (range of strain change $\Delta\varepsilon$) was used. Interpretation of this parameter was shown in Fig. 8 on the example of loops obtained for two stress levels (σ_a=320 and 340 MPa). In Fig. 8 there were shown changes in range of strain $\Delta\varepsilon$ in the function of the loading cycles number on succeeding stress levels obtained for both types of specimens.

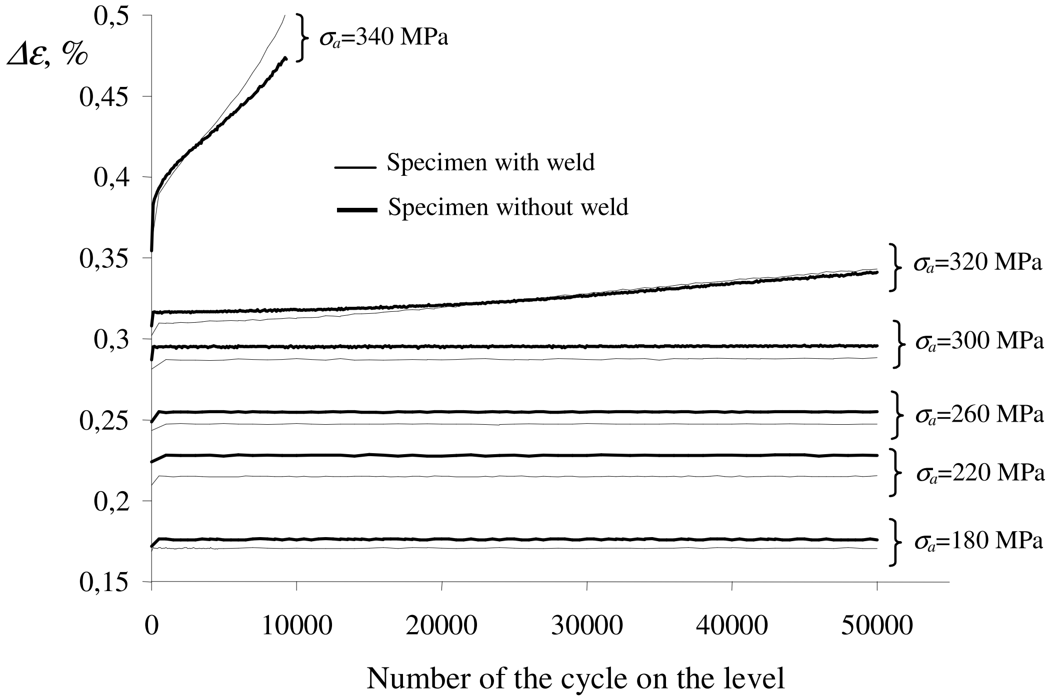


Fig. 8. Range of strain change $\Delta\varepsilon$ of the specimen in relation to the loading cycles number and stress level

Basing on the location of curves of the range of strain changes $\Delta\varepsilon$ it can be found that specimens with weld is characterised by smaller range of strain changes than the specimen without weld. However, those differences are very small and practically disappear on the highest performed levels of stress amplitude (σ_a=320, 340 MPa). On these levels significant increase of strain range is also observed.

Narrower strain range $\Delta\varepsilon$ on the individual loading levels of the specimens with weld can be explained by its diversified material properties in the area of measuring length (about 30 mm). The welding material (about 10 mm) is characterised by significantly higher strength parameters than strength parameters of joined elements. The above observation was verified in many works, among others, in the work [1]. Diversification of cyclic properties of the specimens with and without welds is illustrated by mutual location of diagrams in $\varepsilon-\sigma$ coordinates system (Fig. 9). These diagrams were obtained by joining coordinates describing the vertices of hysteresis loop on the succeeding levels of loading (Fig. 7).

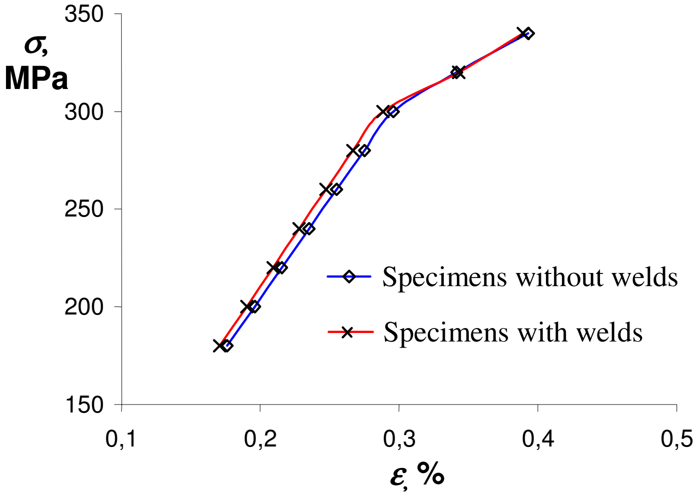
Quantitative similarity of specimens strains which were recorded on different levels of loading was confirmed by fatigue life results. The specimens with and without welds cracked on similar stress levels. In Fig. 9 there were confronted results of total life N_c (Table in Fig. 9b) obtained for the specimens with and without welds.

The results of fatigue life obtained under gradually increasing loading were used for the fatigue limit calculations. Calculations were performed according to the description presented in point 2. In calculations, there was used the equation (1) of fatigue diagram obtained from the fatigue tests of the specimens made of 18G2A steel. During calculations of fatigue limit, the optimization procedure was accepted, which allows to find a parameter b (for which cumulative sum of damages in gradually increasing loading described by relation (2) is equal 1,0) when constant factor of fatigue curve a is given and base number of cycles N_g is assumed.

In the tests as a base cycles number of fatigue $N_g = 10^7$ was accepted. Obtained results of fatigue limit calculations for specimens with and without weld are shown in Table 1.

Basing on the presented results it can be stated that both kinds of the specimen have similar fatigue limit Z_{rc}. It is equal accordingly: Z_{rc}=212,4 Mpa - for the specimen without weld and Z_{rc}=218,6 MPa- for the specimen with weld.

a)



b)

Table 1. Results of fatigue tests

Sample type	Sample no	σ_{ai}	n_i	N_c
1	2	3	4	5
Without weld	Pr1	320	5800	355800
	Pr2	340	2100	402100
	Pr3	320	35000	385000
With weld	Prs1	340	4250	404250
	Prs2	340	21060	421060
	Prs3	320	35560	385560

Fig . 9. The results of fatigue tests: a) loading program, b) results of fatigue life

The fatigue limit can be approximately estimated when temporary tensile strength of the material R_m is known. On the basis of analysis of many previous tests results it was found that fatigue limit Z_{rc} for standardized or thermally improved carbon steel and alloy steel is equal about 0,35R_m [9]. Basing on the results of static tests, which are shown in point 3.1, fatigue limit of specimens with and without welds was determined. Obtained calculations results are presented in Table 2 (column 5).

Table 2. Fatigue limits from tests and calculations

Type of specimen	Specimen marking	Z_{rc} (Locati) MPa	R_m MPa	$Z_{rc}=0,35R_m$ MPa
1	2	3	4	5
Without weld	Sample PR1	205,3	546,7	191,3
	Sample PR2	218,1		
	Sample PR3	213,9		
	MEAN	**212,4**		
With weld	Sample PRS1	217,2	545,2	190,8
	Sample PRS2	224,5		
	Sample PRS3	214,1		
	MEAN	**218,6**		

Basing on the obtained results it can be stated that the fatigue limit determined with the use of static tensile test data is lower than fatigue limit defined with the use of Locati method.

4. Summary

Basing on the comparative analysis of fatigue tests results (shape of cracks and fatigue life) it can be stated that welds present in specimens have no significant influence on them.

The results obtained in the paper confirm the literature data which state that fatigue life of welded joint when exposed to mechanical treatment is comparable with the fatigue life in specimens made of original material (without welds).

Accelerated methods of calculating the fatigue life (Locati method) and methods based on the static tests results allow to estimate roughly the fatigue limit.

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