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CHARPY TOUGHNESS OF VIBRATED MICROSTRUCTURES

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The aim of this study was to investigate the influence of vibration on impact toughness of weld metal. Studies were carried out on two welds, of which one had been welded with applying vibration during welding. From test plates samples were made to simulate heat affect in combination with or without vibration after solidification. This way conditions at multi-pass welding were simulated. According to different conditions Charpy toughness on non standard specimens and fracture appearance were observed. Vibration during welding benefits impact energy of weld metal, especially if weld metal undergoes further heat treatment.

Key words: *welding, vibration, SAW, Charpy toughness*

Charpy žilavost vibriranih mikrostruktura. Namjena ovog članka je istraživanje utjecaja vibriranja na udarnu žilavost zavara. S namjenom istraživanja zavarena su dva zavara s istim parametrima, s tim da je jedan od zavara tijekom procesa zavarivanja bio podvrgnut vibraciji. Iz probnih ploča uzeti su uzorci koji su bili dodatno grijani u peći. Neki uzorci su bili dodatno vibrirani u peći. Tim postupkom simulirano je višeprolazno zavarivanje. Mjerena je Charpy žilavost na nestandardnim uzorcima i analizirani prelomi obzirom na različite uvjete grijanja i vibriranja. Vibracije za vrijeme zavarivanja povećavaju udarnu žilavost zavara, posebno ako je zavar podvrgnut naknadnom toplinskom utjecaju.

Ključne riječi: *zavarivanje, vibracija, zavarivanje pod praškom, Charpy žilavost*

INTRODUCTION

The primary purpose of vibration treatment of welded parts after welding is influence on residual stress distribution and minimization of distortion of welded structures. Many articles describe benefits of vibration on reduction of internal micro stresses after welding, often with measurement of deflection of primary strait welding parts [1 - 6].

When measuring residual stresses, researchers usually do not pay attention to impact and fracture toughness of the weld. Prohaszka et al. [7] examined residual stress reduction on low-carbon unalloyed steel, but he also measured hardness, impact toughness and tensile strain. He compared specimens, which had been heat treated at different temperatures and had been held there for different periods. According to tests, results show a slight increase in toughness with vibration. Similar results were obtained by Kalna [8] with comparison of different mechanical treatments of the weld joint during and after the welding. He recognizes a shift of the transition temperature of notch toughness to lower temperature by 20 °C.

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The number of articles dealing with formation of microstructure of welded joints on account of vibration is rather small. The main reason is probably the fact, that it is usually vibrated after welding, when vibration energy is to low to cause such changes. Freedman et al. and Garlick et al. [9, 10] argue in their articles the influence of the vibration during casting. Refinement of crystal grain is proportional to volume change during solidification. In the case of aluminum casting Fisher [11] recognizes smaller grain size, reduction of porosity and faster solidification of samples vibrated during solidification. Crawmer [12] on the contrary argues no effect of vibration during welding on weld refinement. The reason is short cooling time in comparison to casting. He also does not find any changes in microstructure. Benefits of vibration on grain refinement are described by Tewari and Shanker [13], Hebel and Kreis [14], Xiaowei et al. and Weite Wu [15]. The reason for refinement is breaking of dendrits, which causes more randomized, disoriented and smaller grain of weld bead microstructure. One of the benefits is also faster degasification of the weld [16].

Changes in grain size and orientation are more effective with sub-resonant vibration [14, 17]. Ferrite crystals tend to be aligned according to the direction of the applied stress when vibration and high heat input are applied [18]. Hebel

[14] argues that better mechanical properties can be achieved by sub-resonant vibration during welding due to the change of microstructure of weld to fine grained. When vibrated after welding there is no sufficient energy available for activation of microstructure changes. Starkey [19], Klauba and Mel Adams [20] and Weidner [21] have not noticed any microstructure changes caused by vibration.

EXPERIMENTAL PROCEDURE

For the purpose of experimental work the base material Niomol 490 K (FeE 500KT; Euronorm 137-83) was selected. The welding groove was milled out from the base plate with dimensions 25×200×1000 mm. The groove was 8 mm deep with 45°opening. Two welds were welded with SAW process. Filler material was flux cored welding wire Filtub 128 (F 9 A 8-EC-G; AWS-SF A-5.23) with FB TT (SA FB 1 55AC H5; EN 760) welding powder. After welding under two different conditions, un-vibrated and vibrated during welding, samples for simulation with dimensions 11×70×100 mm were cut out from the weld. In Table 1. there are designations of test plates with preparation conditions. There are four base groups. Samples were un-vibrated or vibrated during the welding and un-vibrated or vibrated during annealing to temperatures between 300 and 500 °C. The procedure of annealing and/or vibrating took 20 min. For samples vibrated during annealing, system shown in Figure 1. was used. It should be mentioned that always two samples were vibrated in the oven together; one sample had been un-vibrated and another vibrated during welding. So both samples were treated with the same conditions. After heat treatment six Charpy specimens were cut out from each sample. Charpy specimens were made with non standard dimensions 8×6×50 mm with fracture surface dimensions 6×7 mm. Crack orientation was through the weld, with crack propagation in direction of welding. Testing temperature for the test was – 20 °C.

Table 1. **Designation of simulated specimens**
Tablica 1. **Oznake simuliranih uzoraka**

		vibration	
without heat treatment	as-welded	un-vibrated during welding	vibrated during welding
		K21	K31
with heat treatment		vibration	
		vibrated during annealing	
	°C	un-vibrated during welding	vibrated during welding
	300	K22	K32
	400	K23	K33
	500	K24	K34
with heat treatment		vibration	
		annealing only	
	°C	un-vibrated during welding	vibrated during welding
	300	K25	K35
	400	K26	K36
	500	K27	K37

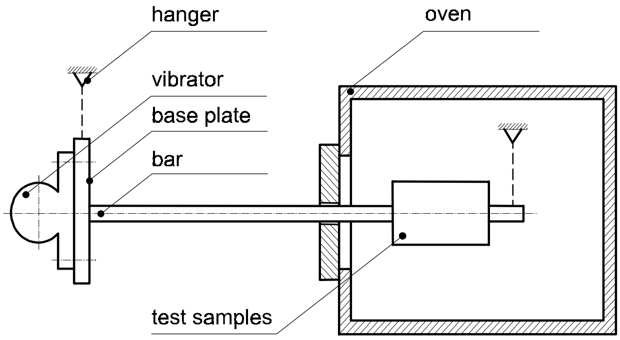

Figure 1. **Vibration set-up**
Slika 1. **Shema uređaja za vibriranje**

EXPERIMENTAL RESULTS

Results of toughness measurement are compared for specimens un-vibrated during annealing (Figure 2.) and vibrated during annealing (Figure 3.) separately. In each figure the results are grouped according to the temperature of annealing. Left column in each group represents weld un-vibrated during welding, the right one represents the weld vibrated during welding. Simulated conditions are compared to heat untreated (as-welded) condition, too. Each value represented in diagram represents average value of four test samples. To compare to values, which would be achieved with standard Charpy specimens with dimensions 10×10×55 mm, the values should be multiplied by the factor $k = 2{,}61$, according to results of previous research work on the same material for the selected testing temperature.

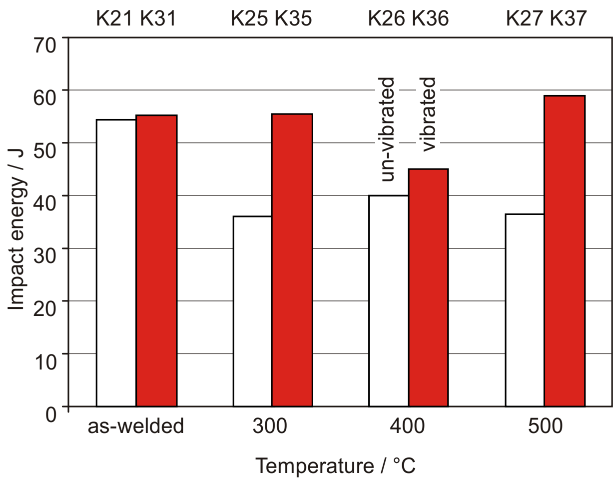

Figure 2. **Impact energy of samples un-vibrated during heat treatment**
Slika 2. **Udarna radnja uzoraka nevibriranih tijekom zavarivanja**

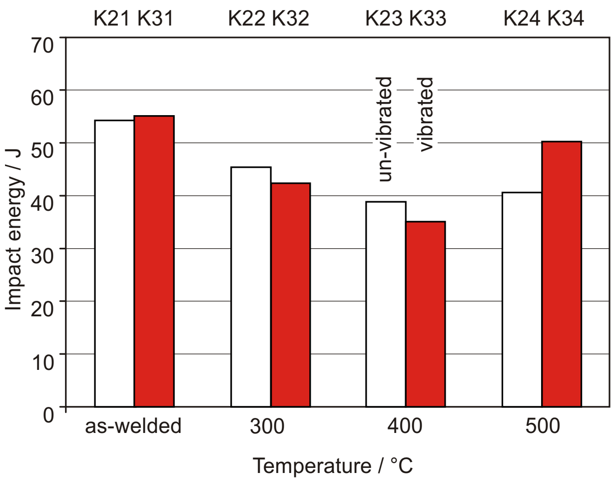

Figure 3. **Impact energy of samples vibrated during heat treatment**
Slika 3. **Udarna radnja uzoraka vibriranih tijekom zavarivanja**

Not all annealing and vibrating conditions were selected for fractographical examination. In Figure 4. as-welded (un-

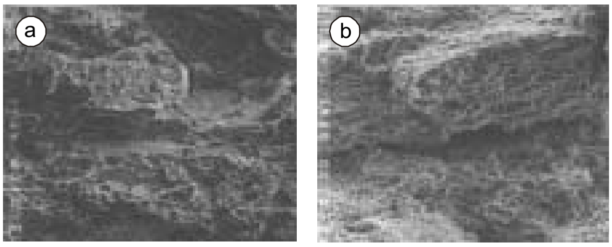

Figure 4. **Fracture appearance of as-welded samples, SEM, 540x: a) un-vibrated during welding, b) vibrated during welding**
Slika 4. **Prijelom uzorka bez dodatnog toplinskog utjecaja, SEM, 540x: a) ne-vibriranih tijekom zavarivanja, b) vibriranih tijekom zavarivanja**

vibrated and vibrated) specimens are compared. Because of big difference between specimens un-vibrated and vibrated during welding and heated to 500 °C without vibration, the fracture appearance is taken into observation (Figure 5.). All photographs from fracture appearance are

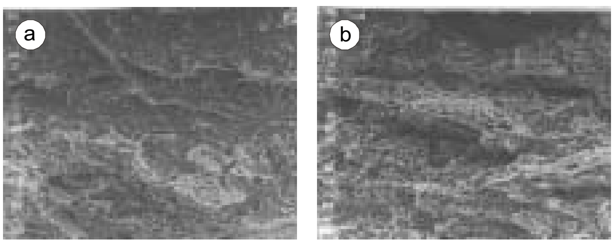

Figure 5. **Fracture appearance of samples heat treated to 500 °C, SEM, 540x: a) un-vibrated during welding, b) vibrated during welding**
Slika 5. **Prijelom uzorka zagrijanog na 500 °C, SEM, 540x: a) ne-vibriranih tijekom zavarivanja, b) vibriranih tijekom zavarivanja**

taken in the same place of Charpy sample, about one millimeter from the center of the machined notch.

DISCUSSION

In former investigations it was already established that changes in weld toughness according to vibration during welding occur. There is an increase in impact energy and specially in fracture toughness [22]. Investigations mentioned were performed on multi-pass weld. On multi-pass weld it is difficult to differ between effects reached with vibration during welding on weld metal and effects obtained with vibration after welding. Namely, a part of weld is already solidified during the welding of next pass. There is a question, if the positive effect of vibration is the result of effects of vibration during welding on solidifying weld or it affects also properties of previous welded passes, which are already solidified. Does the heat of the next pass affect toughness properties in the same way if the weld was vibrated or un-vibrated? Because it is difficult to examine the properties of a single pass in multi-pass weld, the simulation was the better choice. Principle purpose of simulation was a comparison between weld not affected with temperature of next pass and welds affected with temperature and vibration of next pass. The major part of the multi-pass weld remains practically unaffected by temperature of the next pass, but it is affected by vibration at lower temperatures. This condition could be described as vibration after welding.

Temperatures chosen for simulation were under Ac_3 temperature and under the temperature of recrystallization. As already mentioned, it is the temperature that majority of solidified weld metal do not reach. Over the temperature of recrystallization changes in microstructures may occur which could efface the effects of vibration. With vibration in the oven we simulated the part of solidified weld, vibrated because of vibration of the next passes. To increase effects, the time of vibration was longer than in real welds and it took about 20 minutes.

Results in Figure 2. argue, that there is a positive effect of vibration during welding on impact energy of the weld. For single pass welding (Figure 1. - K21, K31) difference seems not to be significant. But if these welds were affected by temperature, the weld metal, which had been vibrated during welding retained its impact toughness, whereas for welds un-vibrated during welding impact toughness was decreased.

Vibrating can somehow inhibit processes of lowering of impact toughness because of temperature influence after the microstructure is solidified. Probably during the welding such microstructures are formed that heat affect can hardly destroy effects obtained by vibration. Smaller grain size could be one of these reasons.

As seen in Figure 3., vibrating after welding intensifies the effect of temperature, therefore impact energy is lowered with increasing temperature, reaching its minimum at 400 °C. Some precipitation processes could be the reason for that minimum. At 500 °C impact toughness values are increased if vibrated during welding.

Only some specimens were fractographic examined. Figure 4. and Figure 5. show fracture appearance of the Charpy specimens. Comparison between both as-welded conditions shows, that when not vibrated, fracture appearance turns brittle with large smooth surfaces. On the other hand fracture appearance of vibrated specimen exhibits surface implicating ductile tearing, although there is no significant difference in measured values of impact energy.

CONCLUSIONS

There is a positive effect of vibration during welding on impact toughness. Vibration stabilizes microstructures to become more resistant to heat affects that could minimize impact toughness.

Type of fracture turns more ductile with vibrating during welding.

Vibration after welding intensifies effects of heat affect, like microstructural changes, in some temperature ranges. Vibration during welding holds back such changes.

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