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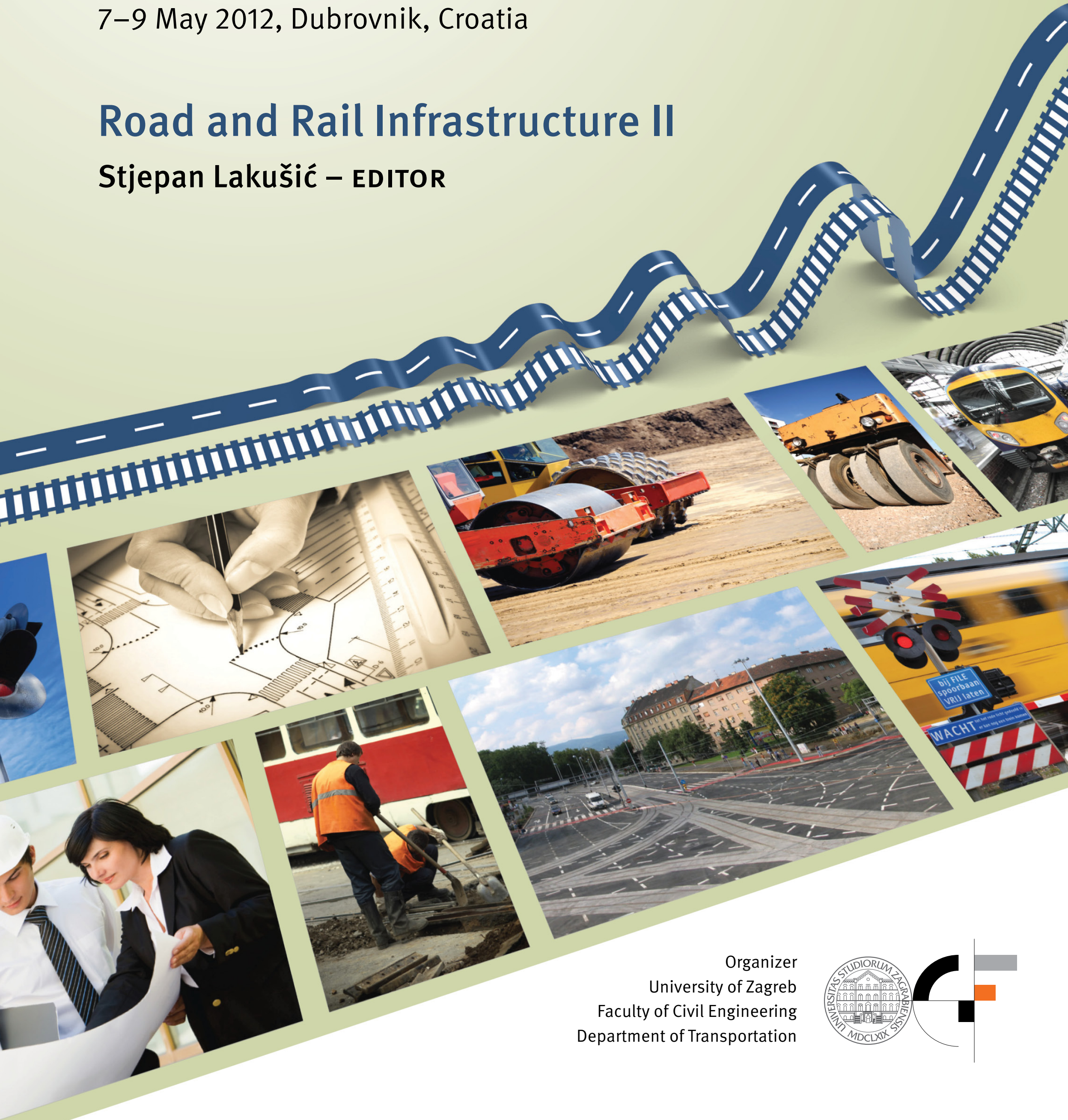
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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ARC WELDING OF GROOVED RAILS – MANUAL METAL ARC WELDING VERSUS FLUX CORED ARC WELDING

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Abstract

Experience collected by the members of the Chair for Railways during 15 years of the supervision of re/construction of tram tracks in the Croatian capital Zagreb and city of Osijek revealed that the largest percentage of local rail damage occurs at the welded rail joints. Poorly performed and unmaintained rail welds cause increased dynamic impacts on the vehicles and the track itself that result in reduced safety and passenger comfort, faster degradation of the track and more frequent need for maintenance of both tracks and tram vehicles. Generally, production of high quality rail welds primarily depends on the applied method of welding, welder's skill and experience and the quality of welded rails steel.

The paper compares two methods of arc welding technique: classical MMAW (Manual Metal Arc Welding) method traditionally used on the Zagreb Municipal Transit System – ZET Ltd network and more up–to–date FCAW (Flux Cored Arc Welding) method which has not yet found a wider application in Croatia. A description of welding technology as well as measurement and analysis of rail surface hardness in the weld zone and rail welds tensile strength has been given. The results of the tests were supposed to answer the question whether the application of this modern welding technology, in addition to shortening the time of welding procedure, also improves the quality of the rail joints.

Comparison of results led to the conclusion that the FCAW welding method is favourable for welding standard grooved rails. It is to expect that the described testing will contribute to faster adoption of this method for welding grooved rails in ZET Ltd network. Also, conducted measurements and analysis are a good background for further research and provide useful, scientifically based conclusions applicable to the everyday engineering practice.

Keywords: grooved rail, manual metal arc welding, Innershield weld, hardness, tensile strength

1 Introduction

Constant increase in tram traffic volume and increase in vehicles speed and loads (consequence of the new modern low–floor vehicles introduction to the Zagreb's tram network) have resulted in increased stresses in track structures. Increase in stresses accelerates the track degradation i.e. track quality decrease.

Dominant factor in deciding on the renewal of rail tracks are the defects generated on the running surface of the rails during their exploitation. Various irregularities of the rail running surface in the form of corrugation, rail head wear and running surface discontinuities are the cause of the additional loads on the permanent way. Research conducted at the Dutch

Railways has shown that 75% of such defects appear on the rail joints [1]. The same problem was observed at the tracks in urban areas, especially in the case of tram tracks exposed to high traffic loads.

Years of Zagreb's tram tracks (re)construction supervision confirmed the results of this research: largest proportion of damage on rail running surface, embedding elements and fastenings occurs in track's welded sections. Presence of recesses on the rail running surface in welded sections, generated during track exploitation, causes the increase of dynamic loads for up to 215% when compared to the loads that occur on a smooth and flat running surface [2].

Since the length of the grooved tram rails is fifteen meters, by means of simple calculations it can be concluded that one kilometer of track, i.e. two kilometers of rails, consists of 134 welds or, in other words, 134 critical points whose poor execution would negatively affect the service life of track. By creating a high quality continuously welded rail tracks we could ensure greater utilization of tram lines and traffic safety, and try to minimize the need for local repair of such critical points on tracks. Such repairs require the closure of tram lines for traffic, which is particularly unfavorable in those track sections where the trams and road vehicles share the same driving surface. Also, because of the defective weld repair procedure which involves cutting, removing and replacing the damaged portion of the rail in the weld zone of a certain length, the total number of critical points on the track increases.

The production of high quality welds primarily depends on the applied method of welding, welding skills and experience and the quality of rails. Rails on Zagreb's tram tracks are welded by manual aluminothermic (AT) and metal arc welding method (MMAW). Regardless of the advantages and/or disadvantages of these welding methods, weld defects are still a major factor in the high cost of construction and maintenance of tram tracks in Zagreb. The appearance of defects in the weld areas is becoming ever more common due to increased loads and the average cost of repair or replacement of the short portion of rail at the weld area can amount to a few thousand euros. For this reason, the question of the necessity of modernization processes in the Zagreb's tram tracks construction and reconstruction arises, i.e. of the introduction of more modern rail welding methods. One such procedure is flux cored arc welding method (FCAW), never before used for welding rails in Croatia.

2 Flux cored arc rail welding method

FCAW is a form of manual metal arc welding method with flux filled electrode and no additional gas protection. Such welding began to be used in the 1950's – it was a new type of electrode that could be used with the application of old welding equipment for arc welding without the need for replacing the burned electrode at the end of the welding cycle.

The processes of FCAW and MMAW welding are very similar: both use the electrode with constant power supply and similar equipment, both include semi–automatic process and have a high level of production and also require three same main components: electricity, metal addition and air protection. Their main difference is in the way of protecting the electrode from the air: FCAW method uses a hollow electrode filled with flux and MMAW method uses gas for protection. Also, FCAW method is during the same conditions and same free length of the electrode more productive: MMAW method can produce an average of 2.3 to 3.6 kilograms of weld per hour and FCAW up to 25 kilograms more [3].

This paper presents a comparison of the quality and durability i.e. tensile strength and hardness of welded grooved rails Ri 60, with welds created using both, FCAW and MMAW, welding methods.

The results of the tests were supposed to answer the question of whether with the application of modern FCAW welding technology, along with shortening the time of welding, satisfactory improvement of the quality of running surfaces rails in welded joints can be achieved.

3 Weld testing

For the purpose of testing four new grooved rails Ri 60 were selected by means of random sampling, two of normal steel quality (grade 700) and two made of wear resistant steel (grade 900A). By welding of rails of the same steel quality, two test samples were created:

- sample 1 – rails (steel grade 900A) welded by FCAW method;
- sample 2 – rails (steel grade 700) welded by MMAW method.

Table 1 Mechanical properties of steel grade 700 and 900A [4, 5]

Sample	Type of rail steel			Tensile strength	Min. elongation	Approximate running surface hardness	
	Steel quality	Steel label		R_m [N/mm²]	A_5 [%]	[HB]	
		UIC 860V	EN 13674-1			UIC 860V	EN 13674-1
1	Wear resistant	R 900A	R 260	880–1030	10	262–304	260–300
2	Normal	R 700	R 200	680–830	14	200–245	200–240

3.1 Hardness testing

Brinell hardness testing was carried out on polished rail surfaces. Polishing was carefully performed, taking into account that the it does not remove the layer of steel thicker than 1 mm. Hardness measurements were then carried out, using digital measuring device Equotip 3, on the running surface of the rails in length of 100 mm to the left and right of the weld axis and on cross section of the rails.

Figure 1 shows the rail running surface hardness distribution diagram for both samples.

It can be seen from the diagram that in case of sample 1 (FCAW method) weld zone is relatively narrow – approximately 20 mm. At a distance of approximately 10 to 15 mm from the weld axis there are peaks in the hardness distribution line in the range of 208-320 HB. Hardness values on the running surface outside weld zone vary around 253 HB.

In the case of sample 2 (MMAW method) weld zone is wider – approximately 37 mm. At a distance of approximately 20 to 25 mm from the weld axis there are moderate peaks in the hardness distribution line. Hardness values on the running surface outside weld zone vary around 210 HB and are within the allowable limits shown in Table 1.

Through the analysis of the results of hardness measurements in the cross section of the rail head, web and base, average hardness values of each sample were determined (Table 2). The average deviation of the measured hardness values are within the recommended limits, except in the case of the maximum deviation of sample 1 cross section hardness, which is slightly higher than recommended.

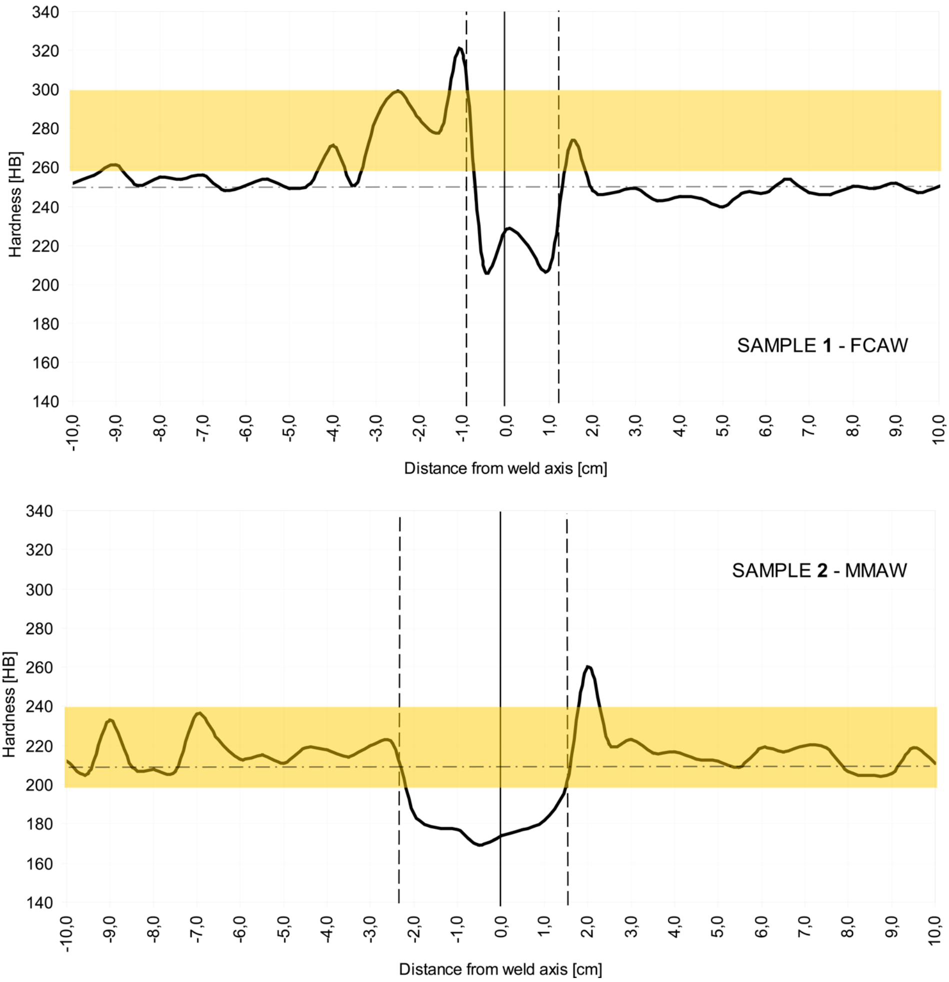

Figure 1 Rail running surface hardness distribution diagrams for both samples

Table 2 Prescribed and average measured rail cross section Brinell hardness values [HB]

Sample	A	B	C	D	E	F
1 (900A)	280	-20 / +30 (-50 / +50)	275	253	208 / 319	-45 / +66
2 (700)	220	-20 / +30 (-50 / +50)	216	210	169 / 260	-41 / +50
A	Base material hardness					
B	Permitted deviation from base material hardness					
C	Average measured rail cross section hardness					
D	Average measured rail running surface hardness					
E	Min/max measured rail running surface hardness					
F	Min/max deviation from base material hardness					

3.2 Tensile strength testing

Hardness testing is the easiest way to assess the quality of rail weld in the first approximation, but as a method of defining weld quality can not be used independently. Hardness testing is therefore usually a method complementary to other methods of determining weld quality, such as tensile strength testing. The tensile strength of the welded rails is tested on short proportional tubes removed by turning from the rails in four positions in their cross–section (Figure 2) [6]. Dimensions of tubes used in this investigation were designed according to HRN EN 10002-1 [7]. While cutting and turning tubes, weld defects were observed at a certain number of positions predetermined for testing. Because of that these positions were excluded from the testing. It should be noted that, as a result of more precise procedure of applying welding material, the observed defects in FCAW method tubes were considerably smaller than those in MMAW method tubes. As applicable for examination and comparison of the tensile strength of different welds, two tubes were selected from the position 3 of the sample 1 and two from the position 2 of the sample 2: tubes 13, 13*, 22 and 22* (the tubes in weld area are marked with asterisk).
Static tensile strength testing was conducted by means of hydraulic press Zwick Roell Z600 that automatically registers applied load and tube's change in length, therefore determining the relationship of stress and strain in it. During tests it was taken into account that the increment of force in time is such that the increment of stresses produced in the tube is ≤10 N/mm2 per second. As presumed, after the maximum force applied all the tubes cracked in sections of the heat affected zone of the weld, and not in the weld zone. Figure 3 shows summarized stress – strain diagram for all four specimens.

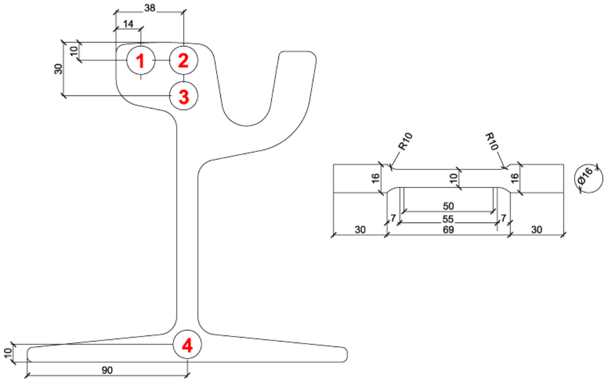

Figure 2 Dimensions of short proportional tube and tube turning points in rail cross–section

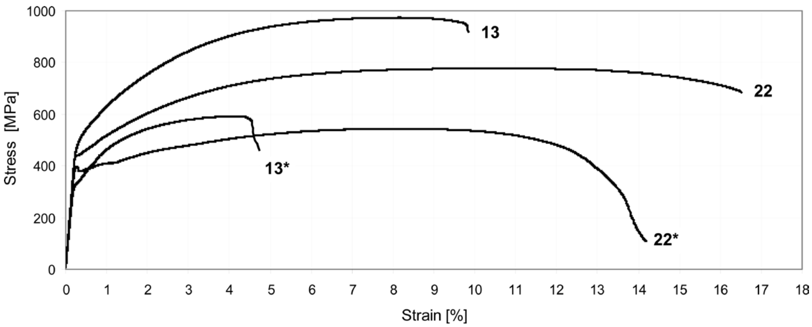

Figure 3 Summarized stress – strain diagram

Table 3 Tensile strength test results

Tube	Max. force tensile strength	Max. force elongation	Fracture force	Fracture elongation
	R_m [MPa]	A_{gt} [%]	R_b [MPa]	A_t [%]
13	973.7	8.1	921	9.8
13*	593.2	4.2	642	4.7
22	777.0	10.3	684	16.5
22*	543.2	8.2	108	14.2

Due to differences in the quality of rail steel, we couldn't directly compare tensile strength values of samples 1 and 2. Their comparison was made by subsequent calculations of the relationship between tensile strength of the tubes, with and without weld, turned out of the same sample.

In both samples the tensile strength of the tubes turned from base material of the sample is greater than the prescribed nominal tensile strength of rail steel.

Test tube 13* on which the tensile strength of the FCAW weld was examined, has a measured tensile strength of 593.2 N/mm2. As expected, its tensile strength is lower than the tensile strength of the rail base material. The analysis of the measured values presented in table 3 revealed that the tensile strength decreased by approximately 37% due to weld.

Test tube 22* on which the tensile strength of the MMAW weld was examined, has a measured tensile strength of 543.2 N/mm2. The tensile strength is also lower than the tensile strength of test tube made ot of base material. The analysis of the measured values presented in table 3 revealed that the tensile strength decreased by approximately 30% due to weld.

4 Discussion

In terms of hardness of the weld defined on the basis of the Brinell test is concluded that the FCAW weld more favorable due to the lower width of heat affected zone i.e. the area in which welding affects the chemical properties of rail steel thus lowering the hardness. However, it is important to note that at MMAW sample lower hardness oscillations in the weld area were observed than at FCAW sample.

Decrease in tensile strength at the weld location makes welds critical points on the track with respect to dynamic wheel impacts on rails. From this aspect MMAW method is more favorable because it has a 7% less decrease in strength than the FCAW method.

Tensile strength testing is the primary method of determining the quality of rail welds, and results obtained from tests described in this paper are relevant. Nevertheless, these results should be taken with caution because the analysis was performed on only two tubes per sample due to weld defects observed during and after test tube turning. For better comparison of the base material and weld material tensile strength, i.e. more harmonized results based on which final decision could be made, more tests should be conducted.

5 Conclusions

According to the literature, main advantages of FCAW over MMAW method are higher weld quality, excellent penetration and good surface appearance of the weld, greater welding speed, lower total cost per weld and increased welding productivity, high stability of the arc and shorter pre–welding preparation process.

Although the tests described in this paper showed that the FCAW method produces welds of slightly lower tensile strength, in general it could be said – with sufficient certainty – that the FCAW method is more favorable for welding of grooved rails than standard MMAW method.

It produces welds with less pronounced decrease in hardness of rail running surface and it has smaller influence on the rail steel chemical properties. This is very important from the viewpoint of increasing weld durability which is a prerequisite for increasing tram traffic safety and comfort and also reducing the cost of tram tracks maintenance.

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