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Structure Improvement of Aluminothermic Welding Joints by Using Modifiers

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***Abstract*—**Aluminothermic rail welding was from the beginning a great success because its low price even in 1895 in Germany. This method is now, widely used all over the world for the railways construction, maintenance and modernization. Instructions give you guidelines for preparing papers for conferences or journals.

After 1989, the welding needs of the potentials beneficiaries (Romanian Railways, Urban Transportation Companies) keep raise because of the railways maintenance and modernization necessity.

The main materials that determine the Thermit (T) composition result from manufacturing scraps all over the country. This can help the environment by consuming these scraps.

The Romanian need for alumino-thermic welding is now by 11300 per year, and in a favourable economical environment, this amount can reach 30000 units.

This paper tries to show the effect of two types of modifiers introduced in the T composition on the structure and properties of an alumino-thermic welding.

***Keywords*—**aluminothermic rail welding, modifier, Thermit.

I. The Aluminothermic Welding Principle

THE alumino-thermic welding is base on the extremely exothermic reaction between iron oxides (FeO, Fe_2O_3, Fe_3O_4) and aluminium powders, by the following formulas [1]-[2]-[3]:

$$3Fe_3O_4 + 8Al \rightarrow 4Al_2O_3 + 9Fe + (3009\,KJ\,/\,3088\,^0C) \quad (1)$$

$$3FeO + 2Al \rightarrow Al_2O_3 + 3Fe + (783\,KJ\,/\,2500\,^0C) \quad (2)$$

$$Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe + (850\,KJ\,/\,2960\,^0C) \quad (3)$$

The Thermit powder (charge) reacted in the crucible and after that, the welding process started (see Fig. 1).

Thermit powder Welding process welding joint
Fig. 1 The welding process [4]

The molten steel temperature as a result of aforementioned reaction is about 2500ºC.

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The amount of added alloy, inclusive modifier will decrease molten temperature below 2100^0C. The melting temperature must be in concordance with pre-heating rail ends (about 950^0C) in order to avoid under-cooling in contact with cold rail end. It is also very important to insure the cleanness of the mould and melt, because of direct influence on weld joint inclusions rate quality and weldment mechanical properties.

II. Experimental Conditions

This paper exhibit the effect of two types of modifiers introduced in the T composition on the structure and properties of an aluminothermic welding. The aluminothermic welding structure improvement was ensuring by the presence of modifier in the melting. The chemical composition of TRQ Thermit – steel, before and after modifier with $FeSi_{34}V_{25}Ti_{12}$ (M1) and $FeSi_{45}Zr_{35}$ (M2), is indicate in Table I.

TABLE I
Chemical Composition of TRQ Thermit – Steel

Modifier (wt.%)	Unmodified	Modified with $FeSi_{34}V_{25}Ti_{12}$	Modified with $FeSi_{45}Zr_{35}$
C	0.50	0.47	0.46
S	0.018	0.019	0.018
P	0.026	0.026	0.022
Si	0.68	1.62	1.85
Mn	1.37	0.48	0.62
Cr	0.18	0.07	0.10
Ni	0.95	0.10	0.10
Al	0.12	0.055	0.23
Ti	<0.005	0.092	0.006
V	-	0.24	-
Zr	-	-	0.09

There were performed different types of aluminothermic welding, depending of the T chemical composition (see Table II). It was also measured the HBW (SR EN ISO 6506-1/2002) after welding of all types of combinations between the moulds (FF – from France; FRQ – from S.C.Quark S.R.L.) and the Thermit (TF – from France; TRQ – from S.C.QUARK EXE S.R.L.) [5].

TABLE II
Hardness for Different Types of Moulds and Thermit

Weld No.	Weld type	HBW 2.5 (N/mm^2)	HBW 2.5 Mean value	HBW 2.5 Rail end
2	TF-FF	223, 216, 203, 193, 221	211.2	220-250
6	TRQ-FRQ	249, 182, 206, 256, 200, 222	226.6	
3	TF-FRQ	182, 182, 231, 197,207	198.4	

7	TRQ-FF	228, 265, 232, 228, 219	234.4

III. Results And Discussion

A. Qualitative analysis of welding joints structure

In order to characterize the Thermit-steel as a distinctive entity and the alumino-thermic welding of the railways metallographic analysis were perform, these being the second stage of the thermit-steel and welding metallographic characterization of the train and tram railways. The microstructure of the railway active zone (RAZ), shows that the ferrite proportion is below wt.1%, so the steel can be considered an eutectoid one (see Fig. 2) [6].

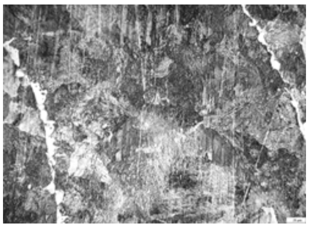


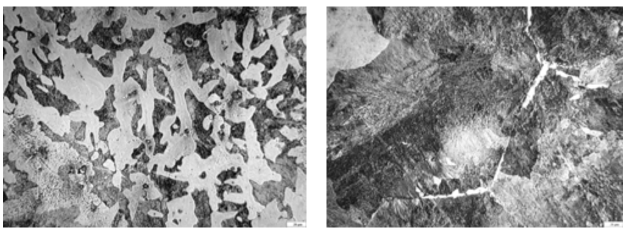
Fig. 2 Microstructure of RAZ; the rail end part

The microstructure aspects, both in the weld zone (WZ), and Heat Affected Zone (HAZ), in mushroom zone (MZ) and heart zone (HZ), before and after modification with $FeSi_{34}V_{25}Ti_{12}$ and $FeSi_{45}Zr_{35}$, are present in Fig. 3 and Fig. 4.

The effect of the modification is visible in both cases and in all parts of the rail. The Widmanstattenn structure is less evident, and the perlite finishing degree is very advanced, ensuring a good tenacity. The etching reagent was nital 2%.

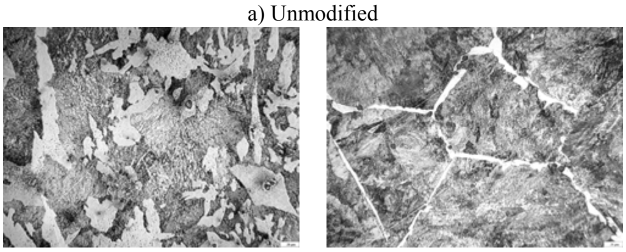
The weld has a bigger and different grain size and distribution in mushroom zone, in compared with the heart one.

The oxide and silicate inclusions are place mainly in ferrite grains and at the interface with perlite grains boundaries.



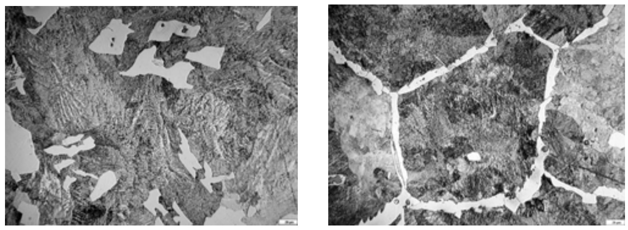
WZ HAZ

a) Unmodified



WZ HAZ

b) Modified with $FeSi_{34}V_{25}Ti_{12}$

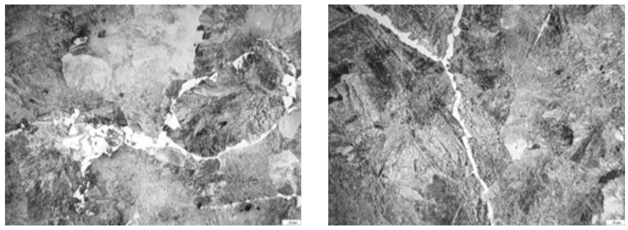


WZ TAZ

c) Modified with $FeSi_{45}Zr_{35}$

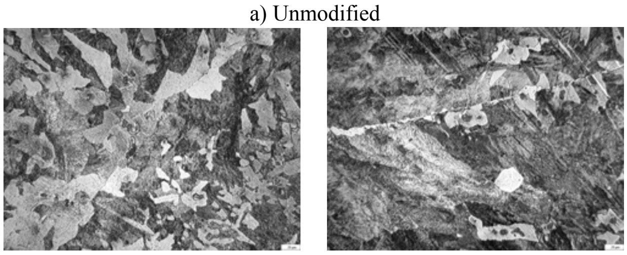
Fig. 3 The microstructure aspects of Thermit – steel in MZ

The inclusion rating is better in mushroom zone, in compared with the heart one, so we estimate a promising static band press, fatigue testing rig and rolling road test.



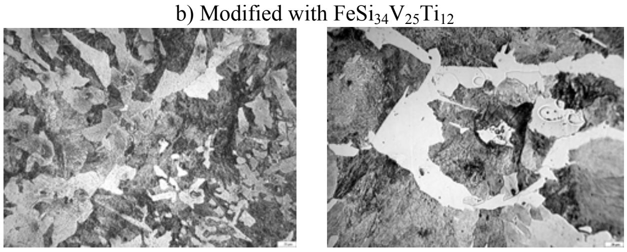
WZ HAZ

a) Unmodified



WZ HAZ

b) Modified with $FeSi_{34}V_{25}Ti_{12}$



WZ HAZ

c) Modified with $FeSi_{45}Zr_{35}$

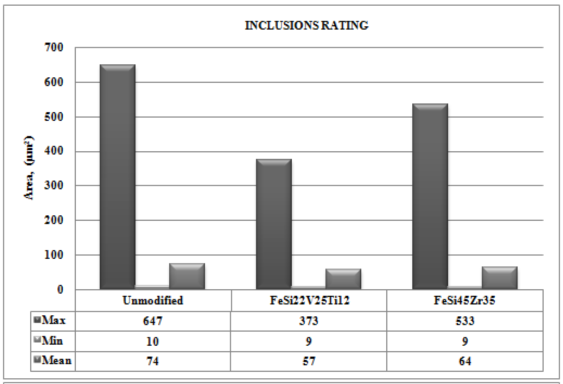
Fig. 4 The microstructure aspects of Thermit – steel in HZ

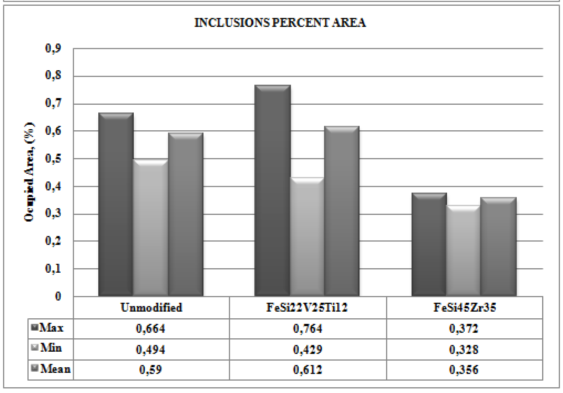
B. Quantitative analysis of welding joints structure

Inclusions rating correlation (see Fig. 5) perform with a image analyses system (Buehler Enterprise System) highlight that the inclusion state is better after modification than before. This fact will ensure an increase fatigue and wear resistance.

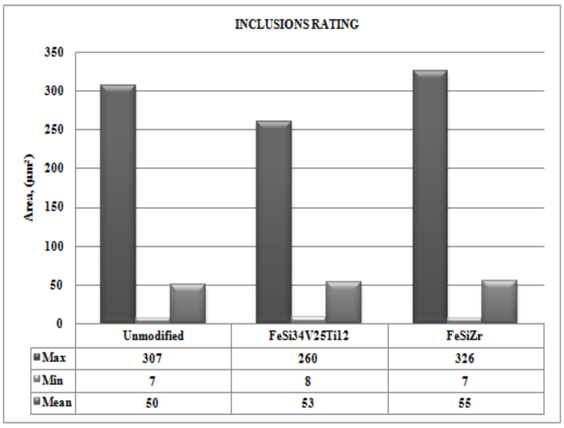
Inclusions rating in MZ are much more uniform after using M1 modifier. Inclusions percent area measured in MZ (mean value decrease from 0.590, to 0.356) is better after using M2 modifier.

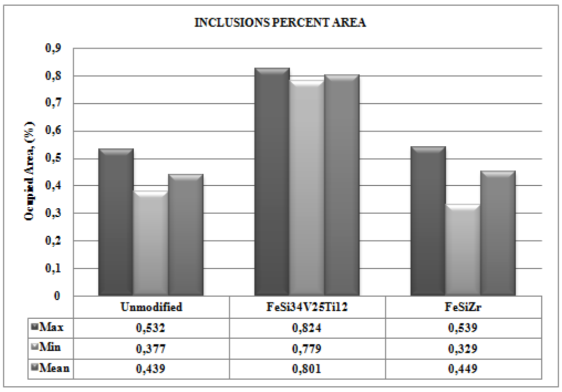
In compare, in HZ inclusions rating registered the same variation, but percent area increase to 0.801after using M1 modifier.





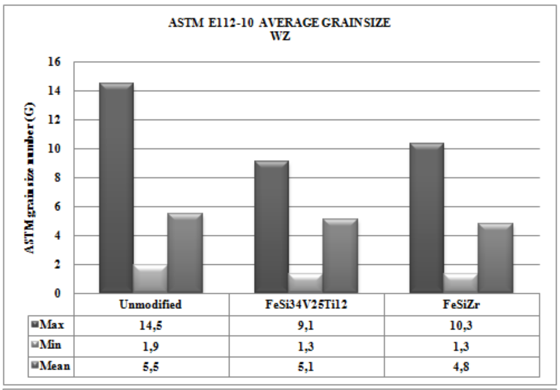
a) MZ

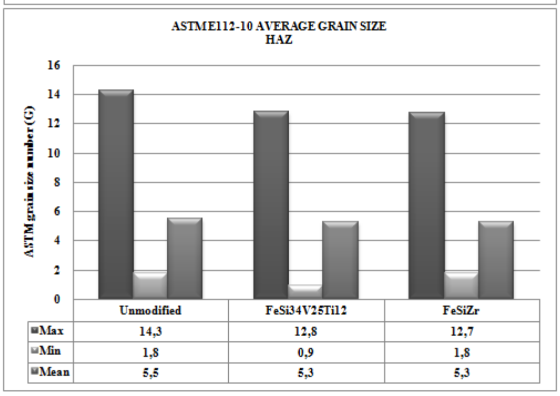




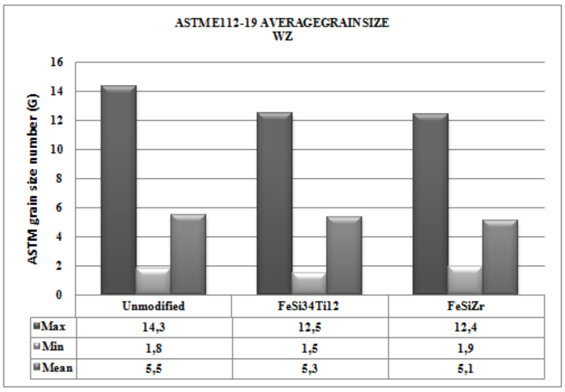
b) HZ

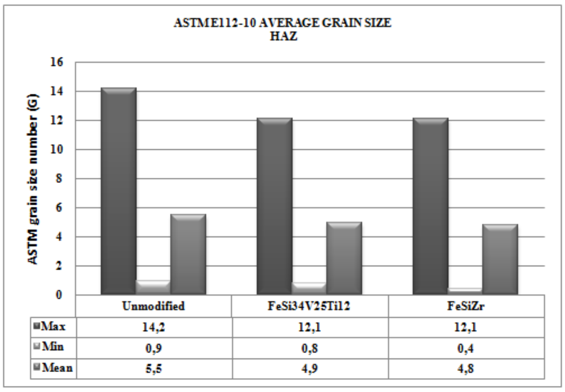
Fig. 5 Inclusions rating correlation





a) MZ





b) HZ

Fig. 6 ASTM E112-10 Average Grain Size correlation

The ASTM E112-10 Average Grain Size (see Fig. 6) lay out the correlation between unmodified and modified states of the Thermit – steel.

The grain size is smaller and uniform in all the railway zones (mainly in RAZ, HZ) and there are no micro pores.

The mean value for ASTM grain size number (G) is comparable in WZ after using the modifiers: 5.1 for M1 in compare with 4.8 for M2, in WZ, and 5.3 for M1 in compare with 5.1 for M2, in HZ.

C. Mechanical Tests

The welds joints were subject of static bending test, sagging and tensile strength tests (SR EN 13674-1, SR EN 10002-1/95), in conformity with quality control system for Thermit-steel (see Table III).

TABLE III
MECHANICAL TESTINGS RESULTS

Weld No.	Weld type	Static band (daNx10^3)	Sagging δ (mm)	Tensile strength σ_r (daN/mm^2)
2	TF-FF	76.800	10	80.000
6	TRQ-FRQ	65.700	8	68.437
3	TF-FRQ	58.600	7	61.046
7	TRQ-FF	78.000	17	81.250

IV. CONCLUSIONS

There were two types of modifiers used to experiment the grain refinement by using alloyed Thermit in aluminothermic railways welding joints, $FeSi_{34}V_{25}Ti_{12}$ (M1) and $FeSi_{45}Zr_{35}$ (M2).

A reduction of Mn content was induced by both modifiers and this fact influences the grain size of the Thermit - steel.

The inclusions rating are better after modification than before. The inclusions are smaller and more uniform distributed in the structure. This fact will ensure a good fatigue resistance and a higher wear resistance.

Using modifiers in Thermit kit can be considered a solution to increase the performance in aluminothermic railways welding joints.

Presented results are base for the near future investigations in order to correlate and optimize the chemical and granular composition of the Thermit kit with grain size refinement and inclusion rating decreasing.

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