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INVESTIGATION OF THE HIGH-MENGANESE STEEL WELDABILITY

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1. Introduction

One of the most loaded railway parts are crossings, especially for the dynamic component of the operation exposure. At present, there is applied mostly cast steel based on austenitic or bainitic microstructure. They are both typical with high resistance to rolling contact fatigue, surface abrasive or adhesive wear, and essential resistance to low-energy brittle failure.

Hadfield´s high manganese steel is unique in the fact that it combines high toughness and ductility with great work-hardening capacity. The wear resistance in rail-wheel contact depends on the surface hardening intensity before operation, and hardening process during operation consequently. Abrasion resistance tends to increase with carbon, but above 1.4% causes a difficulty with obtaining a homogeneous austenitic structure which would be sufficiently free of carbides bordered grains. They are detrimental to strength and ductility [1].

To join the crossing parts made of Hadfield´s steel with the high carbon rain steel means to perform a heterogeneous weld joint with competing demands. The standard austenitic cast steel grade for railway parts contains above 1%C, 11%Mn, while the wrought rains are made of the pearlitic steel which contains about 0.6 %C, 1.5%Mn and less then 0.5%Si. These two materials bring different physical properties and responses of welding behavior. The carbide precipitation on austenitic grain in the heat affected zone (HAZ) of the Hadfield´s steel welded joint decreases the mechanical parameters and degrades fracture behavior, especially fracture toughness, strength and plasticity [2]. It is well known that fast cooling rate after welding can suppress the carbide creating and perform the sufficient weld quality. However, too fast cooling after welding pearlitic carbon steel leads to martensitic transformation, which collaborates with grain coarsening near fuse line. The high carbon martensite phase brings lack of the plasticity, which is unavoidable for residual stress relaxation after cooling. Coincidence of these two effects often causes cold cracking in the heat affected zone of the rail steel. Preheating, which can bring enhancement of the carbon steel weldability is harmful by its influence on cooling speed for austenitic part of the weld joint.

At present, the welding technology for mentioned heterogeneous joints is proprietary in a few countries. The first welding technology for crossing welds was presented in the American patent [3], in that technology the aid of part low carbon austenitic steel was used as an interposed connector between wear resistant high manganese casting steel and carbon rail steel. From then, a few variants of technology were published.

These presented work is dealing with a specific structural changes of the Hadfield´s steel caused by the thermal and stress influence after used welding technology crossing parts to carbon steel rail. The target of the performed analyses was to research the source of damage along weld lines, which are explored on the surface of the welded rail profiles by capillary test, performed after machining weld joints.

2. Experimental procedures, used methodology

The subject of the presented analyses were welding joints between two austenitic steels. The first one was Hadfield´s cast steel for crossing profile, the second one was the low carbon stainless Cr/Ni steel with rail profile, made as an insert part between high manganese and carbon rail steel. The composition of the investigated steel are presented in ***Tab. 1***. Castings were subjected to standard heat treatment. The analysed welded joint Hadfield´s steel and the insert material was not annealed after welding, while the welded joint of the insert material and carbon steel has to be annealed in order to release the residual stress of welding.

Tab. 1 *Chemical composition of investigated steel [wt%]*

	C	Mn	Si	P	S	Cr	Ni	Nb
High manganese steel	1,08	11,8	0,52	0,029	0,005	0,09	0,04	-
Stainless steel	0,07	0,46	0,58	0,015	0,014	19,2	8,20	0,84

After machining weld joints in the final shape there appeared defects, along the fusion zone line. In order to find out the source of this problem, it was unavoidable to investigate influence of the used welding parameters on the original quality joined steel. From the practical point of view it is essential to predict next damage growth, especially in case of continuous cracks presence and lack of the toughness due to carbide precipitation.

With aim to investigate source of real observed damages were performed:

- Macrostructural analyses for description of the range and location defects in connection with the position sublayers HAZ with typical structural differences.
- Structural and phases analyses of the fusion zone and thermal affected zones of both steels, study of structural changes under thermal and stress welding influence.
- Chemical – energy difraction x-ray microanalyses and identification selected phases imperfections with influence on the observed damage.

Equipment employed:

Scanning electron microscope TESCAN VEGA 5130 SB, energy dispersion X-ray spectrometer Quantax 200 Bruker, optical metallographic microscope Neophot 32, monocular magnifying glasses (magnification 20x and 40x).

Etching: 4% Nital, Vilella-Bain

Analyses were performed on the several profile sections – see ***Fig. 1***, with different surface defects amount observed by capillary test.

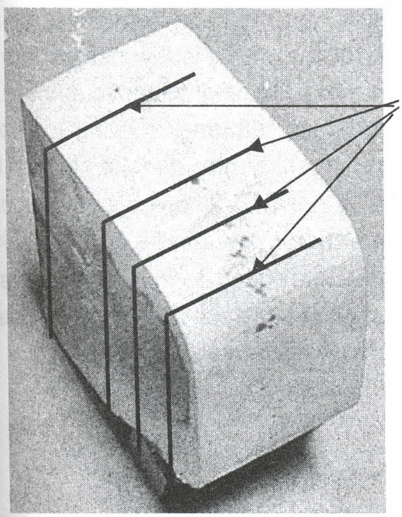

Fig. 1 *The location of the metallografical analyses*

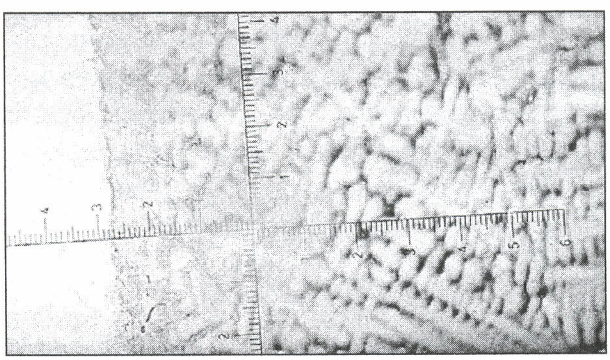

Fig. 2 *(magnification: 20segments = 1mm) Macrostructure of the welded joint*

3. Microanalytical results

Surface observations showed macroscale defects of the Hadfield´s steel in the line about 1-2mm along the weld joint. The macrostructure cast steel with visible primary dendrite morfology presents ***Fig. 2***. Due to low heat conduction coefficient and a high heat expansion coefficient of the austenitic cast steel this austenitic steel tends to casting imperfections presence, which are typically created in according to the primary dendrite boundary. These defects were typically observed only in certain depth under surface, close to weld line they were even reduced by strain influence.

To reveal source of the local material impairments were performed structural analyses of the welded line and damaged layers.

Microstructure of welded line

There were observed no presence of defects in welded line, with very low count of a residual weld metal in width about 100μm. Also microscopy locality of the intermingled steel which were created layers or islands with lack of chromium and nickel did not lead to cracks initiation and so to impairment of the quality.

There were formed a dislocation structure depending on the width of the intermingled zone. Dislocation hardening effect, visible in several sliding systems occurred mainly in the spaces with lower mixed zone, is shown in ***Fig. 3***. This dependence can be joined with difference of the press level along fusion line during welding, for example due to surface roughness welded areas. It is shown that microscopic islands of the contrast phases are created by dislocation martenzite without carbide precipitation. It is one of the important factors taken into consideration when are indicated some imperfection in weld joints oh Hadfield´s steel. So it is low carbon form of martensite which is – in the contrary to high carbon steel - keeping better toughness. In analyzed samples was observed only dislocation hardening tendency. Owing to known fact, that austenite transformation to martenzite realizes through intermediate stage of the hexagonal phase ε; at the low strain rate is increasing density, followed by hexagonal phase creating and finally at the higher level strain rate martenzite phase arises, marked as a ferromagnetic phase α_2. This responses sequence is related to low stratified flaws energy in analyzed grade of Cr/Ni steel with typical very easy dislocation creating. Due to fast cooling intermingled micro volumes displayed more intensive hardening ability.

Chemical microanalyses

The local changes of the fuzion zone chemical composition were verified by energy dispersion microanalyses. The line analyses (***Fig. 3***) shows more share of the alloy phases. Localization of the eutectic shows the scope of the heterogeneous residual phosphorus content after casting, e.g. in the primary structure.

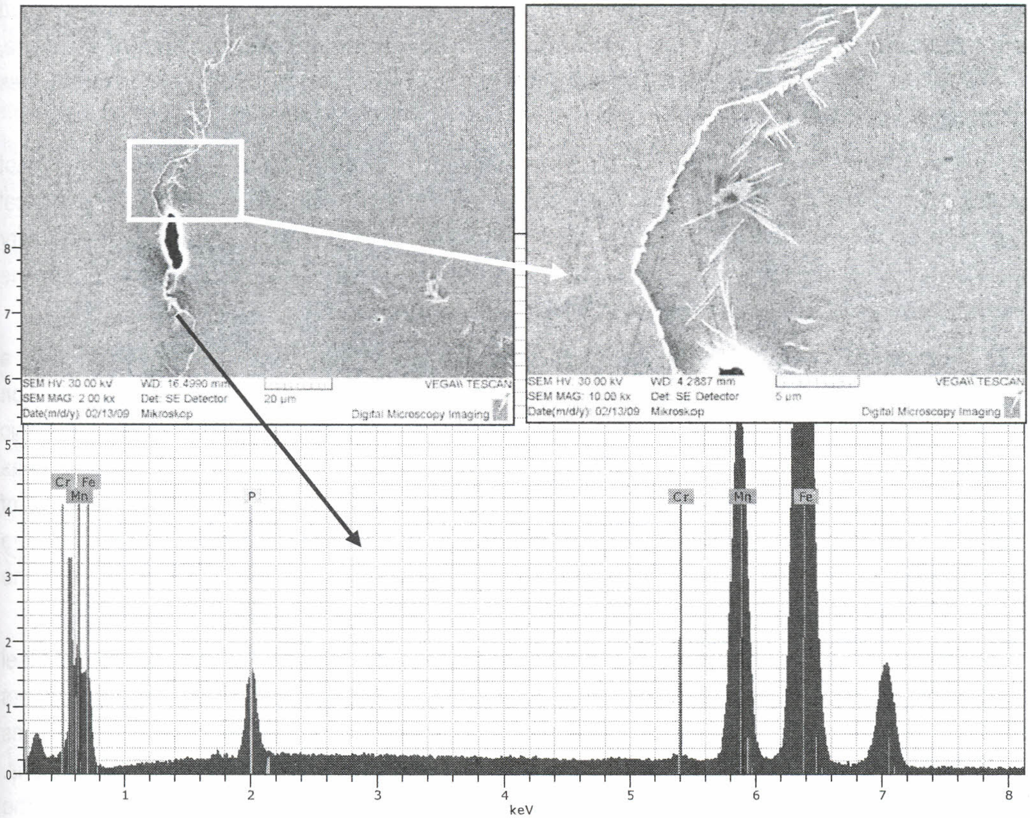

Fig. 4 *(magnification 4,000x)*

Identification of the observed secondary phases

Fig. 5 *Chemical composition of the phosphide eutectic*

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El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
P	15	K-series	4,32	4,74	8,20	0,2
Cr	24	K-series	0,34	0,38	0,39	0,1
Mn	25	K-series	22,58	24,76	24,14	0,6
Fe	26	K-series	63,96	70,13	67,27	1,6
		Total:	91,20	100,00	100,00	

4. Discussion and conclusions

The structure of the Hadfield´s steel in the cast condition consists of austenite, secondary carbides, and commonly a phosphide eutectic and troostite. After standard heat treatment of the castings we obtained in this case homogeneous austenite structure, with only very smooth distribution of carbides without orientation along grain boundaries or retained eutectic.

Performed analyses revealed renewed eutectic creating due to welding heat loading. It means the real cooling rate after welding isn´t sufficient to suppress typical heterogeneous phases and allows rising of the phosphide phases. This is very detrimental process followed by lost of the plastic capacity and decohesion along the secondary phases under thermal stress influence consequently.

The chemical composition of the phosphide eutectic has remained uncertain over a long period. Moreover, it has often been ascribed to secondary carbides. The application of microanalytical techniques recently, has made it possible to determinate the basic constituents of this eutectic: P, Mn, Fe and C. The phosphide eutectic investigation was the aim of the study a number of works. It has been shown that the form and amount of the phosphide eutectic in the Hadfield´s steel depends on many technological factors, the chief of which are the cooling rate after casting, the heat treatment conditions, and the chemical composition [4].

This work was concerning the influence of these conditions on the Hadfield´s steel weldability. As we can conclude the propensity to the hot tearing of certain layers appears due to rebuilding of the primary heterogeneous phases. The observed eutectic formations shape agrees the typical form after casting into raw sand models in production conditions. D. Shulik [4] revealed the same type of phosphide phases in the microstructure of the casting after air cooling that contained phosphorus percentage less that in analysed case (he investigated influence of 0,016%P). In this state the phosphide eutectic is globular in form and surrounded by needle shaped carbides. The higher cooling rates, achieved by pouring into shell moulds produced by the lost wax method for example, leads to suppress eutectic formations. The microstructure of castings with 0,051% P were investigated with the presence of an eutectic with a globular form, even after cooling in water from 1100°C, in which case they were located either at the grain boundaries or in the spacing between the dendrite branches.

The real phosphorus content in the evaluated castings overhangs the safe limit, even for the pearlitic steels [5]. Usually, hot tearing susceptibility increases with S or P content. It has been shown with experimental support from chemical analysis of the compounds appearing on the hot tear surfaces, that the addition of elements which form highly stable solid carbides, e.g. Ti, can be beneficial in reducing the volume fraction of residual eutectic liquid and so make the casting less prone to hot tearing [6]. The analyses, performed in this work, prove the phosphide phases with carbide creating as a secondary phases in connecting to appearing of the welding joints defects. The distribution and the count of this detrimental phases associates with used technological parameters. As we could observe, material is sensitive to hot tearing in very narrow zone, only in a part of the heat affected zone close to fusion zone, under the full reaustenitization process.

From the practical point of view is important the fact, that investigated defects initiation is connected with presence of the phosphide eutectic. The next damage growth is lead along carbide bordered lines. It means, the significance for the operation of these welded parts is limited by reach of the structural degradation. In the investigated conditions is danger of the next development can be restricted by decreasing thermal influence in selected profile parts.

Acknowledgement

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Resumé

VÝZKUM SVAŘITELNOSTI MANGANOVÉ OCELI

Eva SCHMIDOVÁ

Příspevek presentuje výběr analýz v rámci výzkumu svařitelnosti materiálů pro kolejové aplikace. Uvedeny jsou výsledky řešení provozního problému, kdy heterogenní svarový spoj austenitické lité oceli pro železniční srdcovky a standardní kolejnicové oceli vykazoval vady podél svarového rozhraní. Provedené rozbory vedly ke zjištění působícího degradačního mechanizmu. Konkrétně byl prokázán vznik sekundárních fází, které se tvořily v reakci na výchozí heterogenitu v obsahu fosforu. Vznik fosfidického eutektika a zároveň jehlicových karbidických fází po rozhraní s matricí představuje specifickou reakci materiálu na lokální rozdíly v rychlosti ochlazování po svařování.

Summary

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Along the fusion zone were creating microareas with dislocation structure, with obvious dependance on the width of the intermingled zone. Dislocation hardening effect, visible in several sliding systems occurred mainly in the spaces with lower mixed zone. This dependence can be joined with difference of the press level along fusion line during welding, for example due to surface roughness welded areas. It was shown that microscopic islands of the contrast phases were created by dislocation martenzite without carbide precipitation. It is one of the important factors taken into consideration when are indicated some imperfection in weld joints of the Hadfield's steel. So it is low carbon form of martensite which is – in the contrary to high carbon steel - keeping better toughness. In analyzed samples was observed only dislocation hardening tendency.

After machining weld joints in the final shape there appeared defects, along the fusion zone line. In order to find out the source of this problem, it was unavoidable to investigate influence of the used welding parameters on the original quality joined steel. From the practical point of view it is essential to predict next damage growth, especially in case of continuous cracks presence and lack of the toughness due to carbide precipitation.

In the level about 1-2 millimeters along the fusion zone were found out two kinds of defects, cavities and microscopic cracks, both of them oriented on the grain boundaries. As regards to the material out of the welding influence, we could observe typical presence of the characteristic microscopic interdendritic cavities, without any defects or carbide lines.

On the contrary, in the mentioned layer along fusion line were mainly indicated defects on the coarsened secondary austenitic grains. In addition to this, some gradient of the intercrystalline defects were found out; material tended to higher damage on the outside corners of the rail head. Structural and phase analyses showed creating sharp shaped carbides in connecting to local grain decohesion. Performed analyses revealed renewed phosphide eutectic creating due to welding heat loading. It means the real cooling rate after welding wasn´t sufficient to suppress typical heterogeneous phases and allows rising of the phosphide phases. This is very detrimental process followed by lost of the plastic capacity and decohesion along the secondary phases under thermal stress influence consequently.

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From the practical point of view is important the fact, that investigated defects initiation is connected with presence of the phosphide eutectic. The next damage growth is lead along carbide bordered lines. It means, the significance for the operation of these welded parts is limited by reach of the structural degradation. In the investigated conditions is danger of the next development can be restricted by decreasing thermal influence in selected profile parts.

Zusammenfassung

DIE UNTERSUCHUNG DER SCHWEIßEIGNUNG VON HIGH-MANGAN-STAHL

Eva SCHMIDOVÁ

Der Beitrag präsentiert die Auswahl der Analysen im Rahmen der Forschung der Schweißbarkeit des Materialien für die Schienenanwendungen. Die Ergebnisse der Lösung der Betriebsprobleme sind aufgeführt, wenn heterogene Schweißnaht der austenitischen Stahl für die Eisenbahnherzstück und die Standard-Schienestahl die Mängel entlang der Schnittgrenze hat aufgeweist. Die Analyse führte zu der Entdeckung zu einer Verschlechterungsmechanismus. Im einzelnen, die Entstehung von sekundären Phasen hat nachgewiest, die in Reaktion auf den ersten Heterogenität in den Inhalt von Phosphor haben geschafft. Die Entstehung von heterogenen Phasen auf der Schnittgrenze mit der Matrix stellt eine besondere Reaktion der Materialien auf die lokalen Unterschiede in der Abkühlungsgeschwindigkeit nach dem Schweißen dar.