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DEVELOPMENT OF HIGH-STRENGTH STEEL SURFACING TECHNOLOGY

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1. Introduction, goal of experimental works

Railway crossings belong to the most exposed components of a track structure. Operational load presents very complicated complex of adhesive, abrasive, and mainly contact-fatigue affect, which leads to preferential wear and tear primarily in the point and stock rail area depending on many external factors (such as crosswise and lengthwise slip, actual geometry relation in contact with a real worn wheel profile and the like) in the final result. The possibility of continuous reprofiling of the worn segments is an essential requirement on the material applied.

The selection of material analyses results presented herein refer to the surfacing technology proposal of progressive bainitic steel for railway crossings casting. This material, industrial termed as Lo17MnCrNiMo, is intended for the most load-carrying segments particularly. Its chemical composition together with heat treating leads to the comparison with the original alternative (already applied Lo8CrNiMo) to modification of phases represented and later-on higher yield value mechanical parameters, fracture and notch toughness. Development holder of this material and as well the surfacing technology is DT - Výhybkárna a strojírna, a.s, Prostějov company.

Surfacing technology solved herein came from experimental verification of some filler material alternatives, while the common background was following:

- overlay quality associated with original characteristics of the base material;
- demanded quality of join without a degradation of overlays characteristics;
- all without a need of pre-heat and after-heat of created overlays.

This technology is so attractive primarily because of reducing the problematic heat-cycle requirements that are to be obeyed.

2. Methodology of experimental surfacing followed by material analyses

Experimental surfacing was managed in two sets – one after the other. Initial phase was focused on fundamental testing of two surfacing materials with different structure bases; namely bainit, which is very similar to base material as far as the structure and mechanic characteristics go (possibly influenced by higher content of Cr gives premise of higher abradability); further then austenit, which disposes its typical ability for distortional hardening of loaded layer at high toughness of surfacing metal. Specificly were tested following filler material combinations in this phase:

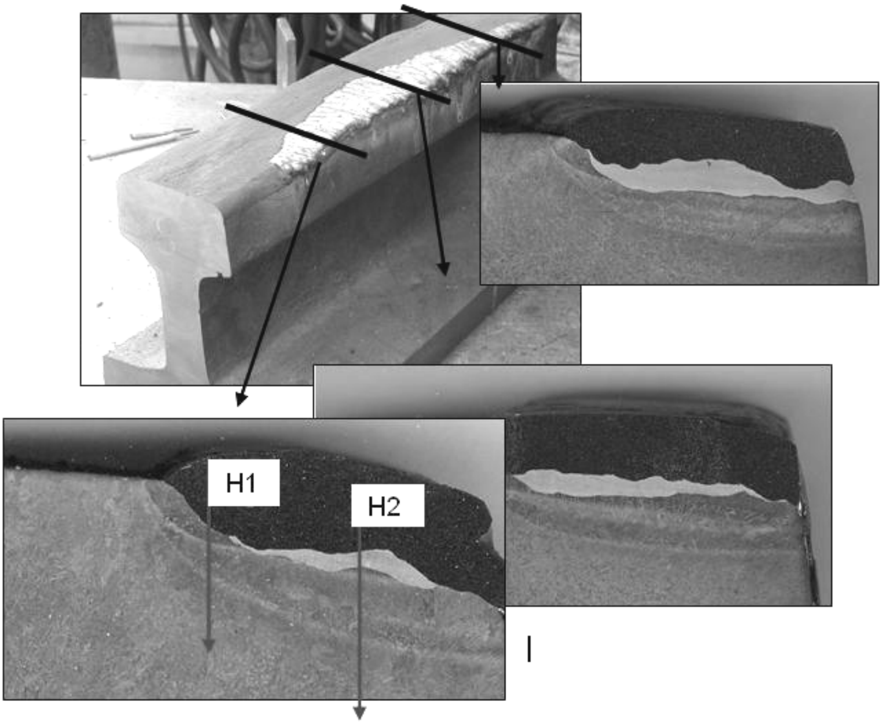
1. tubular cored electrode BMC (further called Cr-Mn)
2. electrode with higher content of Cr (OK 83.53, OK 83.50)
3. tubular wire Tubrodur 15.43 (further called Cr-Ni-Mo)

All the spoken alternatives of filler material were made in two different interlayer versions:

i. silicon irons alloyed by nickel (electrode OK 73.68),
ii. austenitic complex alloyed steel (electrode OK 67.75).

Based on analysis results of surfacing original set came the next phase of experimental surfacing, focused on testing of influence of technological parameters and possibilities of mechanical hardening of welding layers.

Geometry of experimental surfacing considered possible differences in cross-section systematically and also the dimensions of facing metal in dependence on range of operational wear and tear – see *pic.1*. There were solid crosscuts taken from particular surfacing profiles for laboratory analyses needs to study macroscopic inherent defects when occurred, followed by metallographic samples for detailed *structure and phase analysis* of surfacing layers, weld boundary, and heat affected zone. All the analyses made were aimed to complex evaluation of quality with the goal of state a suitable combination of filler material. Quantitative rating of structural changes was achieved by measurement of hardness in lines across the weld boundary. Applied *methodology of microhardness* (HV 0,5) is optimal for catching up the microscopic structural changes on the weld boundary; Simultaneously, it is due to say that it servers only as a comparison test within the measurements done on equal terms (no specification of “surface” hardness and it is impossible to conclude strength characteristics of layers directly from it). *Local chemical microanalyses* catch up the intensity and influence of potential chemical heterogeneity on lines across the weld boundary. The experimental hardening of surface layers issue was analysed separately.



***Pic. 1** Methodology of experimental surfacing and its rating*

3. Selected analyses results

3.1 Structural and phase analyses

Within the rating of experimental set were no defects observed, which could be limiting for the spoken technology, which could cause fundamentally exclusion from the further diagnostics. Several specifications were found at selected alternatives of surfacing steel, and mainly critical areas to achieve a quality joint.

For instance, at austenitic hardening weld deposit based on Cr-Mn with an interlayer from nickel silicon iron it can be specified as “critical” area of peripheral layers; in several cases the absence of interlayer on edge of surfacing groove took an negative effect (see hardness measurement zones “H1” vs. “H2” on *pic.1*). In no area of fusion boundary it came to formation of defects such as cold cracks. Surfacing layers contained rare shrinkage cavities from the last surfacing layer and locally microscopic “hot cracks” in surfacing metal. In this case, the area was concerned, where the problematic formation of weld pass happened, so these microscopic discontinuities cannot be put together with this technology in general.

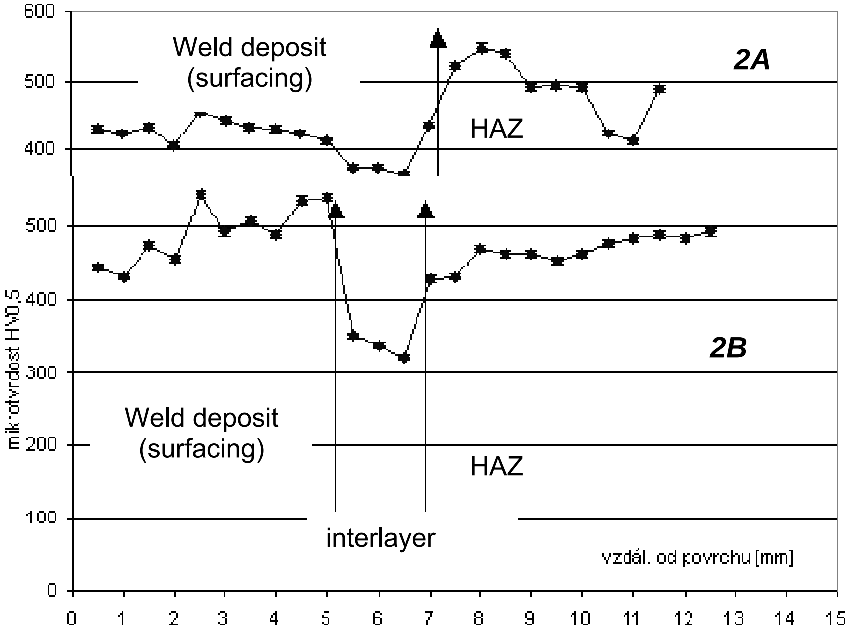
Microhardness lines showed mainly the large dispersion of values right under the boundary of melting. Expected hardening was measured in zone of partial austenitization, in both cases we cannot speak of growth regarding to the original hardness of the steel, which could indicate a critical decrease of tensibility. Possible influence of chemical heterogeneity on the boundary, for example by the technology with use of complex alloyed interlayer (electrode 67.75), was confirmed chemically; possible effects associated with mixing were studied in areas of higher turbulence on the boundary metallographically. In micro-volumes of melting basic material up to the interlayer as well as the neighbouring zones no undersirable structure components were created.

Structural analysis of heat affected zone refered to typical changes in micro-segregation intensity and structure brutification of bainit in the zone of partial austenization. Morphological changes of bainit building did not follow any cardinal hardness changes; an increase was found mainly in comparison with the zone of partial austenization, where the brutification of carbidic phase were followed by partial desolidity of ferit.

In both cases the surfacing of bainitic material with higher content of chromium and type of Cr-Ni-Mo, the assessed cut did show any defects neither in continuity of the weld boundary nor in surfacing metal. In heat affected zone in layer that is very important for quality of bonding it does not come to substantial growth of martensitic part of structure; the most marked effect under the heat influence in this layer was the better demixing at global refinement of bainit observed. Typical is the positive influence of repeated heating in middle areas of surfaced grooves – in comparison with the area of transition onto traverse plane, where it simultaneously did not come to interlayer coating at majority of all the cutting taken (i.e. area of micro-hardness measurement “H1” vs.“H2” see *pic. 2A, 3B*).

Since the proposed technologies are addressed to manual surfacing, it is necessary to think of sure variation of prescribed regime that influences the total rate of heat brought in. The chosen technologies were further tested while the dispersion of technological parameters was controlled. Regarding the chemical character of materials applied, the processes united with lower heat impact (or extreme mixing of materials on the melting boundary) were experimentally tested. The results show that the dispersion of tested technological parameters does not lead to unexpected chemical and structural changes in rate, which could certainly mean a hazard of practical application.

There were such defects found in the range of macroscopic defects, which were classified to belong to creation of existing segment of weld deposit under more research – gas cavities and microscopic shrink holes in austenitic weld deposit of Cr/Mn type; unfused joint on the boundary of interlayer-surfacing metal (practically exclusively in the area of interconnection of weld beads by electrodes), eventually a slag enclosed in. Defects such as hot cracks were not observed in cardinal range.



Pic. 2 *Gradient of micro-hardness “H1(2A)”, “H2(2B)”- weld deposit of Cr-Ni-Mo type; interlayer OK 73.68.*

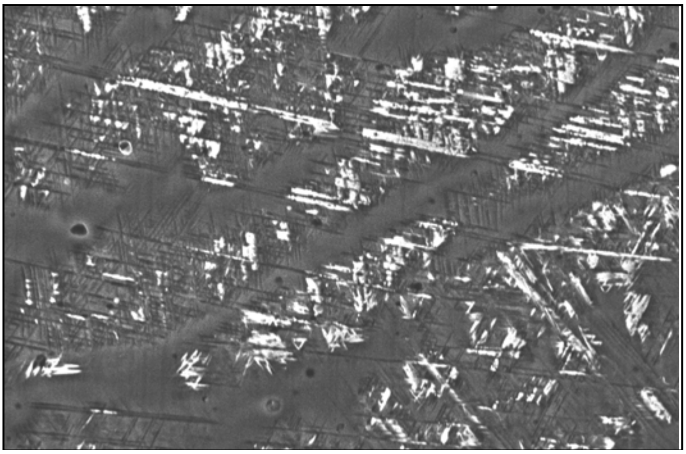
Discontinuities of cold crack kind were not observed. It means that the hardening found in affected layers of base metal was not connected in this fulfillment with critical decrease of plasticity and the thermal strain evoked (locally and structurally) was eliminated by micro-plastic transformation (locally observed in a segment of interlayer). The decisive criterion for selection of a suitable technology was consideration of results on structural and strength gradients of individual boundaries.

3.2 Analyses of deformation hardening

Tested were tends and the mechanisms of deformation hardening at both alternatives of surfacing metal. Austenitic surfacing metal given is able to be deformation hardened without a phase transformation. Tends to low-carbon martensite forms creation were observed in the interlayer in micro-volumes with higher chemical heterogeneity – in an apparent relation to rate of mixing. Dislocation hardening is also the result of inner stress, respectively dilatations on the weld boundary interlayer-base metal (observed also in state without an impact load on surfacing).

In practical point of view it is important that the intensity of deformation hardening while manual eduction of load leads to hardening moved from the original value of c. 300HVm up to c. above 500HVm; it means that the material hardened in this way achieves the hardness of base material in the surface layers. It emerge from evaluation of hardening lines that the hardening value cardinally differs after the way of load – several cases were identified with hardening localized in c. 1,5 mm on surface, and with fluent gradient of hardness from surface layers to the boundary with interlayer.

In comparison with original structure, the new asustenitic surfacing metal plastically changed without any phase transformation after the deformation hardening. Signs of martensite transformation were observed in the area of higher mixing with interlayer. Actual chemist can come under extensive heterogeneity (possible to deduce from Schaeffler's diagram for guidance), hence the very areas of higher mixing were observed. Locally the effect of mechanical hardening of the interlayer was observed – signs of active slip systems (*pic.3*). Tends of phase transformation were observed mainly in volumes of the interlayer paradoxically, i.e. original structurally bainitic. Structural analysis, as the case may be interpretation its results also rely to valuation of microhardness – in micro-volumes it is not prospective to state local changes of carbon content, which are likely to put together with the gradient of hardness. From all the results arises that concrete heterogeneity correspond to silicon forms of martensite; it is spoken of dislocation martensite (silicon form), where mechanical load at the given chemist products so called quasi-martensite, which is only a little hard and still enough plastic. Beside this phase we could as well expect certain amount of hexagonal phase, which occurs only in low-carbon layers with presence of chromium and nickel in some concrete rate and also while cooling down, i.e. could and without moulding



***Pic.3** Microvolumes of dislocalizing martensite in nickel layer (magnif. 5000x)*

3.3 Chemical microanalyses

Goal of the analyses was to state characteristic tends on a background of structure characteristics, eventually approximately passing judgment on potential influence of redistribution of carbide. The methodology of dot microanalyses was used in lines across the weld boundaries, in direction from base material to surfacing metal, with measurement step 500 μm applied. Range of Ni increase in surfacing layers of Cr/Mn type flows from the results, in areas c. upto the middle of the second surfacing layer analysed. Together with interdendritic unmixing it influences the ability of deformation hardening (it explains differences found by hardness reached), above all its development deep into the weld deposit. The boundaries were relatively stable from the local chemical point of view fore bainitic surfacing of Cr/Ni/Mo type.

4. Conclusions

On principal it is necessary to lean the development of contact-fatigue load, where outstanding impact rate of load occurs in addition, against two basic moments:

1. The increase of lifetime in a given regime of load requires an optimal drift into the range of high cycle fatigue, where the influence of fore fatigue process stadium is principally real, which is possible to put together with increase of yield point from the characteristic material impress point of view.

2. Practically running processes of cumulative microscopic deformation (ratcheting) pose claims on the development conditions of surface layers plasticity. That together with anaclastic behaviour of a material influences the circumstances of already initiated damage, i.e. safety in regard of a dynamic load.

Both of the mentioned moments are wide respected by the development bainitic steel and also by the tested alternatives of surfacing metals. Extensive testing fundamentally confirmed the possibility of reprofilation of bainitic steel of a given kind without any preheating with use of an interlayer. As proper technologies for this application surfacing was proposed:

- with tubular wire OK Turbodur 15.43 with the use of interlayer by electrode OK 73.68,
- with tubular cored electrode BMC with the use of interlayer by electrode OK 73.68.

From the results the crucial zone of transition follows from line of joint to the surface travel area. In this zone direct contact between base material and surfacing metal – no interlayer. This situation present a direct source of weld joint harm in interpreted combinations, simultaneously the absence of interlayer can cause higher inner press on weld boundaries. The positive influence of repeated heating of following layers surfacing on HAZ, as well as on the inner shape (grain) of surfacing metal, does not take effect.

Manual impact load testing results in austenitic material of Cr/Mn type, which is manually able to harden above its original hardness of base material – without a phase transformation. Bainitic surfacing metal of Cr/Ni/Mo type does not yield to dynamic hardening under load.

Large amount of dispersion of hardening was identified in area under the surfacing lengthwise the created weld deposits. In coincidence with this “sensitivity” to implementation it is proper to think of automatic surfacing appliance. Automation brings the advantage of stabilized process with and thus also the quality performance, simultaneously there is the possibility for layer preservation by flux and the positive impact regime of surfacing layers cooling.

Acknowledgments

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Literature

1. SCHMIDOVÁ, E. *Provozní vlastnosti nově vyvinuté bainitické oceli pro lité součásti kolejového svršku*, Inaugural Dissertation; Pardubice 2004
2. HLAVATÝ I., FOLDYNA V., KŰBEL, Z. *Aplikace návarů provedených na různých typech kolejnic*. In: Svařování v železniční dopravě 01, ISBN 80-7194-322-3, 2001.

Resume

VÝVOJ TECHNOLOGIE NAVAŘOVÁNÍ VYSOCE PEVNÉ OCELI

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Železniční srdcovky patří mezi nejvíce exponované součásti kolejového svršku. Provozní zatížení zde představuje velice složitý komplex adhezivního, abrazivního, a především kontaktně-únavového působení, které v konečném důsledku v závislosti na řadě externích faktorů (jako je podíl příčných a podélných skluzů, aktuální geometrické poměry v kontaktu s reálně opotřebeným profilem kola apod.), vede k přednostnímu opotřebení především v oblasti hrotu a opornic. Možnost průběžné reprofilace opotřebených úseků je tedy nezbytným požadavkem na aplikovaný materiál.

Zusammenfassung

ENTWICKLUNG DER AUFTRAGSCHWEISSTECHNOLOGIE DES HOCHFESTSTAHL

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Das Bahnherzstück gehört unter meisten exponierten Oberbauteile. Die Betriebsbelastung darstellt sehr komplizierten Komplex von adhäsiv, abrasiv und vor allem Kontaktermüdungswirkung, die letztlich abhängig von einer Kette Externfaktoren zu Vorzugsabnutzung in Spitze- und Backenschienebereich führt. Die Möglichkeit der durchlaufenden Reprofilation von abgenutzten Gebieten ist somit die unerlässliche Anforderung an dem eingesetzten Material.

Summary

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