APPLICATION OF HARDFACING LAYERS FOR RENOVATION FUNCTIONAL SURFACES OF BIOMASS CRUSHER

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Abstract

The article presents the possibility of innovation functional parts of the grinder and results of analysis restoration layers of biomass grinder hammers worn surfaces. Worn hammers, made of Hardox 400 were restored by manual arc surfacing (method 114 STN EN ISO 4063) using selfshielded flux-cored wire - tubular wire Lincore 60-O, produced by Lincoln Electric. Quality of weld deposits was assessed on metallographic cuts, where the presence of internal defects was studied and microstructure of individual weld deposits was identified. In addition to metallographic analysis, there was evaluated microhardness of weld clads according to STN EN ISO 9015-2.

Key words: renovation, hardfacing layers, cladding, lifetime.

INTRODUCTION

On the present usage of the alternative energy sources made from renewable materials becomes increasingly popular. It is interesting from the economic point of view, but mainly from the environmental point of view. One of these renewable energy sources is also the biomass energy. Biomass mostly in the form of silage consists from agricultural plants like the corn, sunflower, wheat and the grass. Biogas – methane is produced by biomass decomposition. Grinding or granulation process is necessary for realization of the waste decomposition, and by that faster biogas production. Grinding or granulation process is realized by using grinders. Biogas is used for generator drive (cogeneration unit) and for power generation. [1] The article presents possibility of innovation of the grinder's functional part, as well as possibilities of the lifetime extension of these functional parts by using hard surfacing.

In the biomass grinders (Figure 1 - 3) conventionally used the steel chain is used for grinding. Its advantage is low price, but its lifetime is significantly limited. Depending on the grinding capacity average lifetime of the chain is app. 2,5 moths. This lifetime is influenced by several tribodegradation factors. Abrasive attrition by

grinded waste has a primary impact. Secondary impact is combined abrasive-adhesive attrition which occurs in a case of abrasion of the inner surfaces of the particular eye of the chain, but especially in a case of abrasion of the inner surface of the first eye about pintle stem, by which the chain is affixed to the top of the grinder, what is documented in the Figure 4 and 5. Besides the combination of these tribodegradation factors the lifetime of the chain is influenced by chemical assertiveness of grinded material, mainly its acidity. Due to acid medium $C_3H_6O_3$ (lactacid) silage consequently settles on the surface of the grinder's cage or inside the eye of the chain, what also accelerates the corrosive processes.

Rapidity of the attrition is negatively influenced also by the presence of the other than organic waste (rock, soil, etc.).[2]



Figure 1 Grinder interior with the top of the grinder and the chain [2]



Figure 2 Biomass grinding in the grinder

Functional part of the grinder is rotating top (head), in which 4 chains are affixed by using the pegs.



Figure 3 Top (head) of the grinder with chain's fixation [2]

Rapidity of the chain attrition is different. Separation of the one of the chains is not rare, what in the grinding process with high revs has destructive impact on the whole grinding cap. By attrition of the chain and the peg together length of the particular chains change (lengthening), what in the case of grinder could cause friction of the edge chain eye about the grinder inner cover, and by that its damage.



Figure 4 Detail of the worn chain eye [2]



Figure 5 Detail of the worn pintle stems (ø 10mm), by which is chain affixed to the top of the grinder

From this reason four chains were within the grinding innovation process replaced by two hammers made from abrasion-resistant material Hardox 400 (Figure 6). Besides the prevention of the grinder destruction when the chain separates one of the reason for innovation was also the possibility of renovation of the functional surfaces of the hammers by the arc hard surfacing. It is possible to multiply extend a lifetime of the hammers by the application of the hardly welding layers at the functional surfaces.

MATERIALS AND METHODS OF THE EVALUATION

Top of the previous grinder with the chain (Figure 3) has a diameter of 220 mm and is made from the material X5CrNi18-10 EN 10028-7.

Chain is made from the steel 10S20 EN 87-70, PN 46-04 grade 100. Length of the chain is 320 mm and it consists from 9 cells.

Taps of the diameter with the diameter of \emptyset 15 and the length of 35 mm which are used for clamping the chain to the top are made from the material X5CrNi18-10 EN 10028-7.

Alternative solution could be the top of the grinder at the Figure 6.



Figure 6 Innovated construction of the top of the grinder

1 - top of the grinder, 2 - crushing hammer, 3 - tap

Top of the grinder (Figure 6, number 1) has a diameter of ø 350 mm and the size 50 mm. It is made from the material X5CrNi18-10 EN 10028-7. Crushing hammers (Figure 6, number 2) are made form by welding of the burnt prepared from plasma from abrasion-resistant material Hardox 400, with the size of 15 mm, which chemical and mechanical characteristics are introduced in the Table 1 and 2. Crushing effect of the four chains is replaced by 2 hammers. Rangy shape of the crushing hammers was chosen with respect to higher efficiency of the grinding compared to the straight shape of hammer (Figure 7).

Table 1 Chemical composition of the material Hardox400 (in % of the weight) [3]

С	Si	Mn	Cr	Al	Mo
0,031	0,421	1,232	0,244	0,035	0,038
Ni	Cu	V	Ti	Nb	Co
0,042	0,008	0,013	0,015	0,017	0,018
W	Р	S	Fe		
0,003	0,01	<0,002	Zv.		

Table 2 Mechanical properties of the material Hardox 400 [3]

R _e	R _m	A5	HB	KV (-40°)
[MPa]	[MPa]	[%]		[J]
1000	1200	10	370-430	45



Figure 7 Welded crushing hammer [2]



Figure 8 Parameters of the hammer and its clamping part [2]

Crushing hammers were made by welding using the method TIG (141 STN EN ISO 4063) in the protecting atmosphere of the mixed gas Ferroline C6X1 from the production of the company Messer Tatragas s.r.o. [4]. Weld joints were prepared in the position PB STN EN ISO 6947 at the equipment Fronius MagicWave 4000 Job according to Figure 9. [2, 5, 6]





Figure 9 Process of weldment preparation [2]

Parameters of manual welding of the hammers are documented in the Table 3. For the welding of the material Hardox 400 two types of additional materials for TIG welding were recommended by the producer of additional materials - company ESAB. For welding of the components which are not exposed to the effect of the corrosive environment additional material OK Tigrod 13.28 was recommended. For weldments which were located in the corrosive environment what a case of the crushing hammers is also, additional material OK Tigrod 309L was recommended. Its chemical and mechanical characteristics specified by producer are in the Table 4.

Table 5 Used	parameters of the nammers welding			
Welding	Welding	Flow of the	Polarity	
current I	intensity U	protection		
[A]	[V]	gas [l/min]		
120 radix	12 radix	13	DC -	
150 cover	15 cover			
layers	layers			
Electrode		Additional 1	naterials	
Wolfram-thorium		OK Tigrod 309L –		
from Abicor Binzel		ø 2,4 x 1000 mm		
ø 2,4 x 1	75 mm			

Table 3 Used parameters of the hammers welding

Table 4 Chemical composition (in % of the weight) nd mechanical properties of the additional material OK Tigrod 309L (W 23 12 L - EN ISO 14343-A [7]

С	Si	Mn	Cr
< 0,03	0,5	1,8	24,0
Ni	Mo	Cu	Fe
13,0	< 0,3	< 0,3	Zv.
R _{p0,2}	R _m	A_5	KV (-60°)
[MPa]	[MPa]	[%]	[J]
430	590	10	130

Hammers are connected to the top of a grinder by the taps (Figure 10). Taps are made from the same material as the top of a grinder, X5CrNi18-10 EN 10028-7. Tap allows steering movement of the hammers, but mostly the simple removal of the hammers in a case of their maintenance or replacement.

Besides an extension of the lifetime by the replacement of the chains in return for the hammers alternative solution of the construction of the top of a grinder allows also the renovation of worn functional surfaces by electrical arc welding, what was infeasible while using the chains.



Figure 10 Demountable connection of the crushing hammers with the top of a grinder [2]

The goal of this experiment was to propose the suitable method and the additional materials for the renovation of worn surfaces and to verify the quality of fusion faces by non-destructive and destructive tests. So that it is a renovation of the small amount of the components per year, so-called part renovation, it is possible to think about manual arc hard surfacing methods from the economical point of view.

Following methods according STN EN ISO 4063 come on force:

- 111 manual electrical arc hard surfacing by using the wrap electrode (MMAW),
- 114 manual electrical arc hard surfacing by using filled electrode with own protection (FCAW),
- 131 manual electrical arc hard surfacing by using the consutrode in the protection atmosphere from inert gas (MIG),
- 135 manual electrical arc hard surfacing by using the consutrode in the protection atmosphere from active gas (MAG),
- 136 manual electrical arc hard surfacing by using the consutrode in the protection atmosphere from active gas,
- 137 manual electrical arc hard surfacing by using the consutrode in the protection atmosphere from inert gas,

For renovation by the hard surfacing it was chosen the technology of the manual electrical arc hard surfacing by using the wrap electrode (FCAW), 114 - STN EN ISO 4063. The reason for the option of this technology of the hard surfacing was the possibility of the hard surfacing without using the protection atmosphere (inert or active) and compared to the method 111 also automatic mode of the additional material feeding that provide continuous hard surfacing. Disadvantage of this technology compared to the methods 131 and 135 which used solid wires is the necessity of the slag removal from the surface of particular layers of weld deposit, however its benefit compared to these technologies is an offering of the wide range of the chemical compositions of the tubular wires.

Process of hammers renovation

At the beginning of the process there was a cleaning (preliminary treatment) of the rangy surface of the hammers from the impurities (remains of the biomass grinding) by using the pneumatic adjutage at the equipment TJVP 320, from production of the company Škoda Plzeň. As an adjutage instrument there was used an alumina trash with a mean diameter of the grain $d_z=0,75$ mm.

Renovation of crushing hammers surfaces was realized at the equipment Cloos MC 303. Tubular wire Lincore @60-O (MF10–GF–60–CG – DIN 8555-83 was the additional material for the hard surfacing. Chemical structure of this tubular wire specified by producer Lincoln Electric is in the Table 5.

Table 5 Chemical structure (in % of the weight) of the additional material Lincore 60-O

(MIF10-GF-60-CG - DIN 8555-83) [8]				
С	Si	Mn	Cr	Al
4,2	1,3	1,6	25,4	0,6

Weld deposit of the hammers surfaces was performed in the two layers from the reason of the elimination of the mixing the weld metal with the basic material. Parameters of the hard surfacing are presented in the Table 6.

Table 6 Used parameters of the hard surfacing

	Base layer	Cover layer
Additional material	Lincore 60-O	Lincore 60-O
Diameter of the wire d [mm]	1,6	1,6
Flow of the hard surfacing I [A]	240	280
Welding intensity U [V]	27	30
Polarity	DC +	DC +
Extrusion of the wire [mm]	15 - 20	15 - 20
Position of the hard surfacing STN EN ISO 6947	PA	РА
Speed of the hard surfacing [m/min]	6	6,5

Used methods of the weld joints and weld deposits revision

Quality of the weld joint s and weld deposits were judged using the non-destructive and destructive methods.

Grade of the weld joint s and weld deposits was judged using the visual control according STN EN ISO 17637. Also the presence of the surface defects such as interstices, overflow of the weld joints, the size of the weld joints, pass camber etc. were evaluated. Appropriateness of chosen additional material for the welding as well as welding parameters using the method 141 were tested on the cross section by the macroscopic and microscopic analysis according STN EN 1321. Also the quality of the welding layers was judged. Shape and size of the weld joints were evaluated by the macroscopic analysis. Under quintuple enlargement of the magnifier Eschenbach the presence of the cracks, interstices, pits and pickups inside the weld joints as well as inside the welding metal were tested. By using the light microscope Olympus CX 31 the microstructure or the basic material, weld joints, heat influenced areas and also the welding layers were analyzed.

For better visualization of the structures of tested high-alloy weld joints, the quaternary glue was used (methanol, hydrogen nitrate, hydrochloric acid, glycerin) in compliance with the literature [5].

On the cross sections the microhardness according Vickers in terms of STN EN ISO 9015-2 was examined. Measurements were realized at the equipment Shimadzu HMV 2 according the diagram in the Figure 11. The power of 980,1 mN affect the indentor. Measured patterns have been prepared in accordance with STN EN ISO/DIS 6507-1.[9-12]



Figure 11 Diagram of the microhardness evaluation on the sections of the fillet weld joints

Microhardness evaluation was realized also on the cross sections of weld deposit through the both welding layers, heat influenced area to the basic material.

ANALYSIS OF THE ACHIEVED RESULTS

By visual control according STN EN ISO 17637 the presence of the external defects wasn't identified on the surface of the weld joints or weld deposits.

In the Figure 12 there is a macrostructure of reversible fillet weld. By the macroscopic control there wasn't identified the presence of the inner defects on the sections of the fillet welds. In the symmetry there were found some little deviation

but these were within the bounds of tolerance. Depth of the weld joint corresponds with the used welding parameters. For enlargement of the weld joint it is possible to recommend the welding flow increase up to 150 A in the radix and up to 180 A in the cover layer.



Figure 12 Macrostructure of the reversible fillet weld of the crushing hammer [2]

In the Figure 13 there is macrostructure of twolayer weld deposit. On the macrostructure there is obvious the height of welding layers, sketch of the base pass weld, as well as the area of the heat influence. There wasn't identified the presence of the inner defects on the examined sections.



Figure 13 Macrostructure of the two-layer weld deposit

Basic material HARDOX 400 (Figure 14) has structure formed by line fain grain ferritic-perlic matrix, inside which occurs grains of bainite and martensite.



Figure 14 Basic material Hardox 400

Very interesting findings was presence of the temperable line martensitic structure which passed exactly through centre of the tin plate (Figure 15).

This line appeared probably during the termomechanical treatment of the tin plate at the point of its production.



Figure 15 Detail of the martensitic structure passing the centre of the tin plate

The zone where weld metal merges into the basic material is in the Figure 16. Under the weld joint it was possible to identify two heat influenced area of the basic material.



Figure 16 Microstructure of the weld metal passing to the basic material

Area marked as HAZ 2 is formed by fain grain bainite-martensitic structure with the acicular ferrite and pseudo eutectoid ferrite. Area HAZ 1 is formed by coarse-grained structure with the ferrite, perlite and martensite. Somewhere it was possible to observe Widmanstätten structure.

Weld metal of the additional material OK Tigrot 309L has a structure formed by austenite and δ -ferrite (Figure 17). Using the constitutional Schaffler diagram it is assumed content of δ -ferrite inside the weld metal in an amount of 20 %.



Figure 17 Microstructure of the weld metal (OK Tigrod 309L)

Structure of hard surfacing metal prepared by additional material Lincore 60-O is in the Figure 18. Austenitic or eutectic structure includes a big amount of primary carbides. Presented dendrite formations are oriented at the direction of weld deposit cooling.



Figure 18 Microstructure of the weld metal (Lincore 60-O)

This type of structure tends to the formation of the cod cracks.

The results of microhardness evaluation are displayed in the graph in the Figure 19. Resulting from the curve the maximum values were measured at interval of 279 - 286 HV 0,1 I in the basic material Hardox 400. In HAZ microhardness drops down on the minimum values at interval of 242 - 249 HV 0,1 that were measured inside a weld metal made by additional material OK Tigrot 309L. The curve of measured values of microhardness matches with the chemical structure of used materials and also they are in accordance with declared values from producers.



Figure 19 The curve of microhradness of the fillet weld of the crushing hammer (BM – basic material, HAZ – heat influenced area)

Measured values of hard surfacing metal microhardness are displayed in the graph in the Figure 20. Measurement was realized on the cross sections in 0,5 mm distance out of the weld deposit surface in the direction to the basic material. Twelve measurements were realized.

Maximum values of microhardness were measured on the covering weld layer, namely 832-830 HV 0,1.



Figure 20 The values of microhardness of the samples with cladding

On the values of the base weld layer there wasn't determined significant influence of mixing the weld metal with the basic material, what could happened because of using the small diameter of additional material (Ø 1,6 mm), which doesn't cause intensive mixing of the molten metal during the hard surfacing. In the base layer there were measured values at interval of 828-550 HV 0,1. In HAZ there were measured the microhardness from 540 to 325 HV 0,1. Minimum values from 318 to 286 HV 0,1 were measured in the basic material Hardox 400.

CONCLUSION

In the article there are presented the possibilities of innovation of the functional parts of grinder. Previous construction solution used chain for biomass waste grinding. Its disadvantage consists in short lifetime. As an alternative solution the modification of the top of a grinder and the replacement of the chain by the crushing hammers proposed. Half-finished were product for preparation of the crushing hammers was steel tin plate 400 form which particular components were cut by using the plasma. After that these components were welded by using method TIG with additional material OK Tigrot 309L. Except for this alternative solution of the functional part also other verified method of hard surfacing in order to renovate functional parts of the hammer was suggested, where some hard surfacing layers prepared with additional material Lincore 60-O by manual electric arc hard surfacing with tubular cored electrode with own protection were used. Just this technology is in the present times increasingly used for the renovation of the functional parts of extremely stressed components, materials.

Base on the realized experiments it is possible to point out that proposed additional materials, as well as the welding and hard surfacing parameters are suitable for given type of the components from the abrasion-resistant material type Hardox.

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Literature

- [1] AGRICULTURAL BIOMASS: silage.
 [online]. Available on The Internet:12.9.2013
 <<u>http://www.polnohospodarskabiomasa.sk/i</u> <u>ndex.php?c=3.1.3.1</u>>.
- [2] UHRÍN, M.: Possibilities of modification functional parts of crusher by application of wear resistant materials, Diploma thesis, KTaM, Sj. F. TU v Košiciach, 2013, 91s.
- [3] HARDOX WEAR PLATE: HARDOX 400.
 [online]. Available on The Internet: :12.9.2013
 <a href="http://www.ssab.com/en/Products--services/Products--s
- [4] SHIELDING GASES FOR WELDING -MESSER. [online]. Available on The Internet: 12.9.2013 <<u>http://www.messer.sk/Info__Download/Prospekty/Zvaranie_a_rezanie/Ochranne_plyny.pdf</u>>.
- [5] STN EN ISO 4063 Welding and allied processes. List of welding methods and their numerical marking.
- [6] STN EN ISO 6947 Welding. Welding positions.
- [7] ESAB: OK Tigrod 309 L. [online]. Available on The Internet:12.9.2013 <u>http://products.esab.com/Templates/T041.as</u> <u>p?id=134780</u>
- [8] Lincoln Electric: Lincore 60-O. [online]. Available on The Internet:12.9.2013 <u>http://www.lincolnelectric.com/assets/en_us/</u><u>Products/Consumable_HardfacingConsumables-Lincore-Lincore60-O/c71023.pdf</u>
- [9] STN EN ISO 17637 Non destructive testing of fusion welds. Visual inspection of fusion welding joints.
- [10] STN EN 1321 Destructive testing. Macroscopic and microscopic analysis of welds.
- [11] STN EN ISO 9015-2 Destructive testing. Hardness testing. Part 2: Microhardness testing of welded joints.
- [12] STN EN ISO/DIS 6507-1 Metallic materials. Vickers hardness test. Part 1: Test method