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SURFACING OF CUTTING EDGES FOR CLAY CUTTING

1. Introduction

1.1. Wear and Maintenance in Mining

Wear or abrasion in lignite opencast mining have a complex appearance and are caused by mining of lignite or by excavated material. Wear often takes the form of abrasive wear and develops on the conveying systems, e.g. bucket-chain or bucket-wheel excavators and also on spreaders and belt conveyor systems. Although there is long-term experience about wear in opencast mining, e.g. wear on caterpillar tracks (base plate, chain link, sleeves and bolts) or on dredging shovels [1], the operating companies are confronted with different situations caused by the ever-changing geological conditions. This challenge is met by research and development via active exchange of experience, further advancement of coating processes and also by developing a new quality for surfacing filler materials. Within the scope of this article, results are presented which refer to the improvement of wear protection on rough-cut cutting edges which are used in the Lusatian opencast mining region. The complete exchange of the cutting edges for a bucket wheel takes 8 hours and requires, moreover, 5 staff workers and auxiliary tools. In this connection, the demand for the increase of the cutting edge service life through more effective wear protection speaks for itself.

1.2. Coating Processes and Alloys

For the machines and equipment which are used in opencast mining, assembly groups and individual parts made of different alloys and also cast parts and forgings are applied.

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Besides the application of work-hardening and naturally hard alloys, other parts are, after manufacturing, also provided with a preventive wear protection by the operating company or by outside companies.

Oxyacetylene surfacing with powder and/or tubular rod or with covered rod is, still today, a widely used wear protection for repair work or for the coating of smaller parts, such as digging teeth. Also, electrode manual surfacing is used for in-situ repair work.

For large-area surfacing, e.g. of wear plates or rollers, the processes: surfacing with self-shielded flux-cored wires (Open-Arc) and plasma-transferred arc welding (PTA) are used. In surfacing with self-shielded flux-cored wires the coating/base metal dilution is, depending on the alloy and the operating conditions, between 20–30% in the first layer while the layer thickness is within the range of 3–10 mm. The typical alloys with the high content of Cr and C and the alloy symbols Fe 14–Fe 16 are, also with regard to requirements and possible application examples, defined in [2]. Typical iron-chromium hard alloys are complex, multiple-phase materials with a structure which consists of a relatively ductile matrix with embedded hard particles. The chromium content is normally between 28 and 35%, the carbon content is within the range of 3.0 to 5.2%. Other alloying elements are, for example, manganese, niobium, vanadium and boron; nickel is found less frequently. Corresponding to the alloying constituents and the cooling conditions and also to their mutual solubility, the complex carbide M7C3 develops as a dominant hard material phase. Flux-cored wires offer a wide application spectrum; their production is inexpensive and the possibility to produce all kinds of alloy in small quantities and with high economic efficiency has clear advantages. The achievable deposition rate in surfacing with flux-cored wires is, depending on the wire diameter, approximately 12 kg/h, the typical degree of dilution with the base metal is 30–35%.

Due to the increasing number of automated production processes and also to the improvement of quality control, PTA surfacing has, during the last few years, gained in importance. Thus, the process-specific advantages allow achievement of high-quality protective layers with a dilution level of less than 10% (depending on the deposition rate and the welding material). The deposition rate quantity is, meanwhile, up to 20 kg/h when fused tungsten-carbide containing (FTC) weld fillers on Ni-base are used. For high-performance applications, mainly NiBSi alloys (sometimes with Cr) with 60% FTC are used. Compared with welding of flux-cored wires, the process is rather complex and expensive. Due to the fact that access to the parts is sometimes difficult, coating of these parts is only possible in a most limited way. In this case, PTA and flux-cored surfacing are complementing one another. While the more simple workpiece surfaces are hardfaced via PTA, the edges and flanges are protected via FTC containing flux-cored wires.

2. Mining-Specific Characteristics

The rock which is overlying the Lusatian lignite mining area consists of tertiary and quaternary unconsolidated rock. Generally, unconsolidated rock is defined as a mixture of minerals, rock fragments and organic constituents with pores which are filled with water, dissolved salts or air [3].

The classification and specification of overlying rock formation is stipulated in different standards, for example:

- DIN 18 196 — classification into soil groups according to grain size and plasticitył
- DIN 18 300 — classification into soil classes according to mineabilitył
- DIN 4022 — classification according to grain size.

Based on the data gained from the geological exploration, a classification of the overlying rock formation [4] has been drawn up for the opencast mines of the Lusatian mining district which, under consideration of geological changes, allows to derive technical-organisational measures for the upkeep. For analysis and information about the upkeeping, the classification of the excavated material into digging resistance- and wear classes is, above all, relevant.

The geological conditions for the pre-cut section of the Nochten opencast mining district have, as from 2003, basically changed due to the strong recess of the proportion of quaternary layers (valley sands) and the increase of cohesive horizons [5]. These geological changes have, in the end, also been the reason for the investigations about hardfacing of the cutting edges of buckets of the bucket excavator, type SRs 6300, which is used in the pre-cut section of Nochten.

The cohesive soil fractions consist mainly of the so-called „bottle clay" which, in a compact form, represents 1st to 4th „bottle clay horizon" (FTH) in the rock mass. The high specific digging resistances of k_L = 60–70 kN/m (linear specific digging resistance acc. to KÜHN) in connection with a higher abrasivity of these soils bring about early wear of the cutting edges and lead to clearly more frequently occurring inacceptable downtime.

In order to ensure that pre-cutting operation is carried out upstream of the overburden conveyor bridge and also to prevent the bridge operations to collide with pre-cutting, 3-shift operation on a 7 day weekly basis has been planned until 2013. This includes 2 repair shifts per week and/ or back shifts. Against this background, the demand for the increase of the cutting edges service life through improved better wear protection is explained since a complete change of the cutting edges for the bucket wheel takes 8 hours and requires 5 staff workers and auxiliary tools. It is, at the same time, impossible to carry out other probably necessary maintenance work on the bucket wheel.

3. Coating of Components

3.1. Welding Problems

Due to the geological characteristics which have been specified above, the wear part „pre-cutting edge", made of the material GS30Mn5, required a solution for the increase of its service life and lesser maintenance intervals. It was planned to carry out the preventive wear protection in two stages. The first stage was carried out using the same self-shielded cored filler wire which had, so far, been used for partly mechanised welding. The surface welds were to be reworked, welding operation was to be carried out fully mechanised. In the second stage, the optimisation of the alloy constitution of the weld filler material was to be carried out, connected with the evaluation of the geometrical design of the surface weld with regard to:

- hardfacing (coating) area and thickness,
- positioning of the surfacing layer,
- development of starting-point crater and crater at the end of bead and
- the closing of the joint edges of the individual surfaces (3 D contour).

In addition, the initial design of the cutting edge geometry was advanced further with regard to energetic points of view. Finally, a comparison with the plasma-arc powder process was carried out.

3.2. Mechanisation and Automation

Not only economical reasons or quality requirements demand the mechanisation of the working places in surfacing with the aim of preventive wear; humanisation of the working place and the occupational safety are also of stringent necessity. In addition, also the saving of filler materials is expected, particularly with regard to the constantly rising prices for raw materials. Simple auxiliary means, such as holding or clamping devices in combination with weld pool backing can already be a valuable help. Positioning systems [6] such as revolving table and/or tilt-turn positioners, turnover devices or carrier trucks also bring about positive effects, independent of the degree of mechanisation or automation. For the welding movements, also carriages, equipment racks or gantries are, beside robot arms, applicable.

3.3. Fully-Mechanised Weld Tests

The weld tests have been carried out with the aim of technological development and the determination of an alloy which is suitable for the respective load case, the determination of the area to be coated, the welding sequence and also of the process parameters. Figure 1 shows the used experimental set-up which was, due to the high number of the areas to be coated and their spatial orientation, relatively complicated.

For the coating, the standard alloy: (FeCr22Nb7C5,2 / Type 61) had been the basis which was then as a modified variant (*A*, *B*, *C* with variation of the alloying elements: Cr, B, V, Nb) deposited with other component coatings.

Table 1 lists the alloys which have been used in the test series.

3.4. Results

Figure 2 depicts the wear behaviour of the different alloys, compared with partly mechanised welding. The weld fillers of the types *A*, *B*, *C* are, with the same coating area, compared with the initial state of the manual weld. The length differences of the cutting edges on the right side, compared with the cutting edges on the left side are resulting from the fact that the cutting edges on the left side have a shorter initial length which was induced by the design.

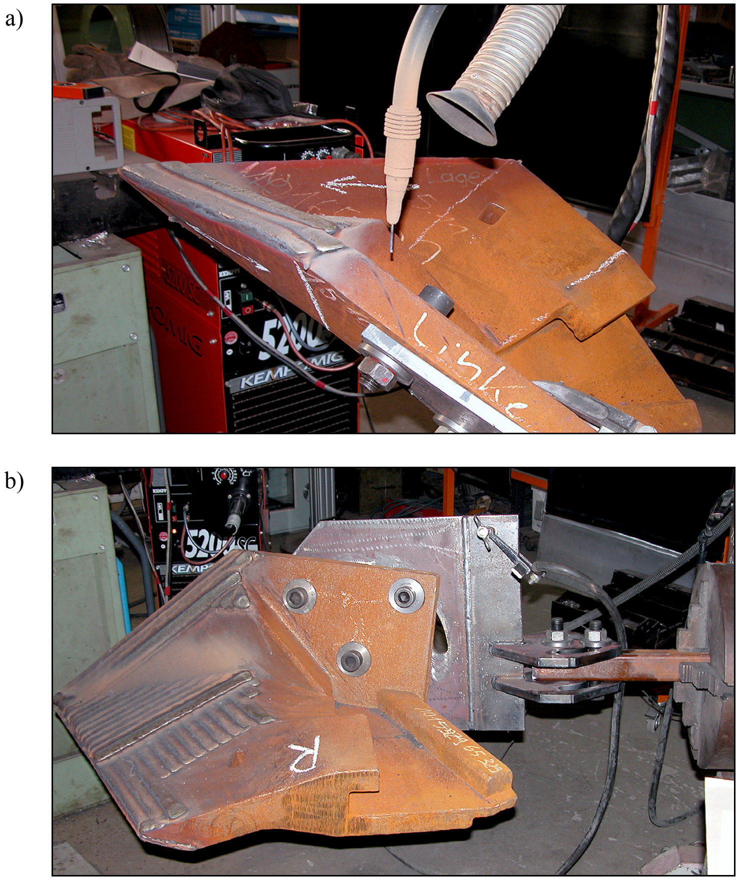

Fig. 1. Equipment and test arrangement in surfacing

TABLE 1
Test Series

DIN EN 14700 Alloy	C%	Si%	Cr%	Others:
T Fe 15-65-G Alloy A	5.2	1.2	22.0	Nb, B
T Fe 16-70-G Alloy B	5.0	1.3	16.0	Nb, V, B
T Fe 16-70-GZ Alloy C	5.0	1.0	21.0	Nb, V, B

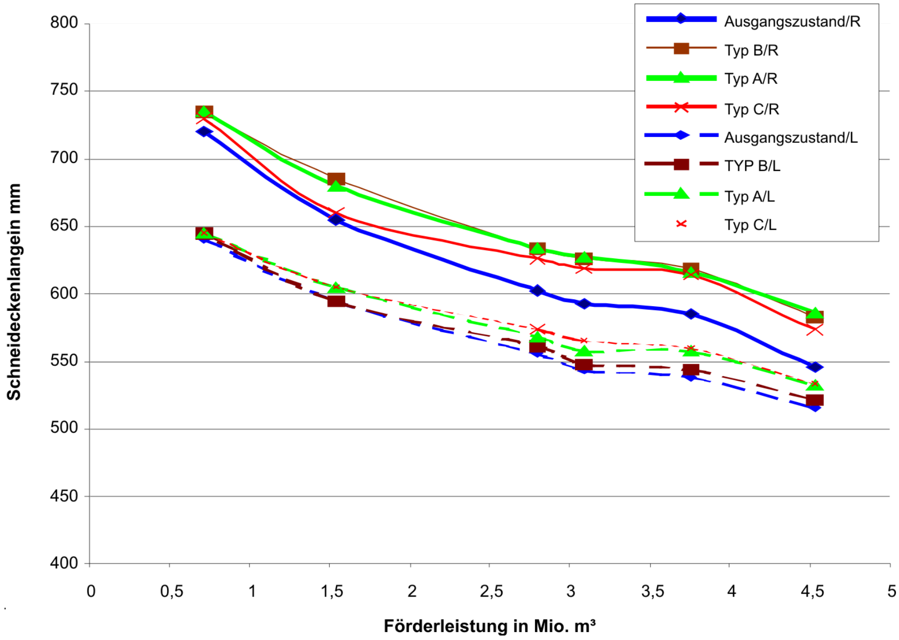

Fig. 2. Wear as a function of the conveyor capability

The comparison of the wear behaviour shows the negative influence of the manual weld which had been carried out partly mechanised. Moreover, the modified alloys with optimised coating area are characterised by a better wear behaviour. This first step towards a new technology which is already connected with the increase of the service life has the following advantages:

- Optimised coating area and coating points (after evaluation of the worn assemblies).
- Adaptation of the process parameters (weld filler material, — type and — diameter, number of layers).
- Fully mechanised welding (defined alloy composition in the wear region of the component).

The evaluation of this test series shows that the service life in the test period has doubled, compared with the former technology.

4. New Geometry of the Cutting Edge

The next step was the transfer of the gained knowledge to a new pre-cut cutting edge geometry. The new design had been developed in a cooperation with the TU Bergakademie Freiberg. Besides the suitability as preventive wear protection which is applicable automatedly, also the cutting capability and the decrease of the energy consumption of the conveyor system have been in the focus of design.

Moreover, the new cutting edge geometry was to be used for process comparisons, where the determination of the flux-cored wire service life was to be carried out in comparison with a PTA surface weld.

The fully mechanised weld allows the comparative evaluation of the technology as a process comparison and gives information about the economic feasibility in dependence of the used weld filler materials (Fe-based, NiBSi + FTC).

4.1. Flux-Cored Surfacing

In order to increase the economic efficiency, the developed technology was transferred to coating by means of robots. For this purpose, a weld robot system, Cloos, type ROMAT 76 AW (ultimate load: 10 kg) with integrated tilt-turn table (ultimate load: 175 kg) was used. Analogously to the welding technology which had been used so far, the automated coating of the new cutting edge geometry was carried out with regard to oscillation width and layer positions. The beads were welded with a width of 15–25 mm with a weld current of 280–300 A, a welding voltage of 27–28 V and a wire diameter of 2,4 mm. As far as the programming is concerned, the shape and positional tolerances in technology adaptation have to be considered due to the high number of surfaces and contours to be coated. That means that tolerances in cast part production and the accessibility will restrict the application of a robot. The projections and undercuts will require manual re-finishing work.

4.2. Plasma-Arc Powder Surfacing

In plasma-arc powder surfacing, analogously to the cored wire electrode welding technology, also the coating area and welding sequence of the surfacing had to be determined besides the determination of the weld filler materials and the parameters. Figure 3 shows, on the left, the surface-welded new cutting edge geometry.

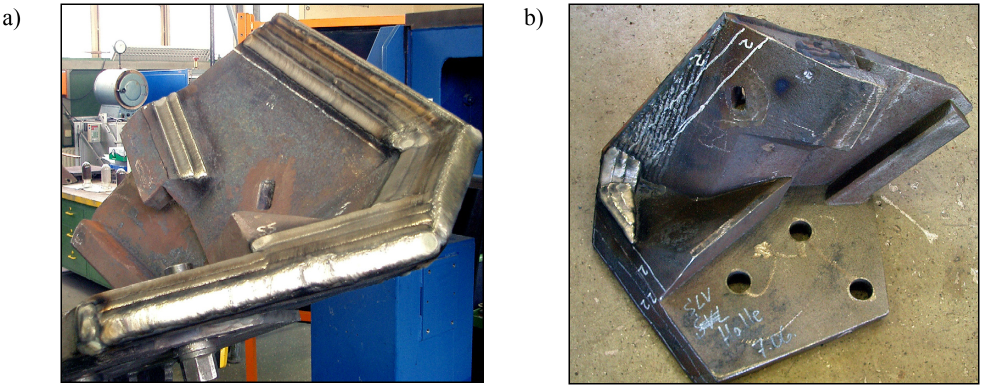

Fig. 3. Plasma-arc powder surface-welded new cutting edge geometry

On the right side, Figure 3 shows the process-related problem in the region of the „gusset cutting edge”. While in surface welding with filler wire the long, free wire-stickout allows free access, the machine/torch dimensions in plasma-arc powder surfacing do not allow appropriate coating of all parts. Those parts were coated using a small hand torch before the surfacing process was carried out.

4.3. Results

Application of the cutting edges which have been coated with both processes showed similar duration of service life. The plasma-powder surface-welded edges show, with the same service life, longer cutting edges. The wear patterns depict the more pronounced cracking behaviour of the cored filler wire surface weld (see Fig. 4). In the region of the projection, the surface layer is no longer existent and suffers, promoted by the crack formation, loss of material at the interior (Fig. 4b).

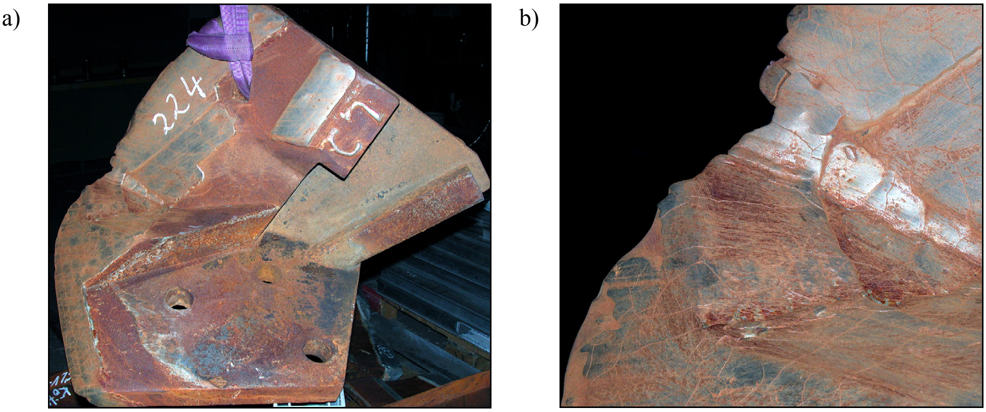

Fig. 4. Worn cutting edge 224 (left 2)/cored filler wire coating

The plasma-arc powder surface-weld shows hardly any cracks in the less loaded areas, (Fig. 5a). The detailed view from the region of the projection (Fig. 5b) shows the comparatively low cracking tendency which is characterised by less loss of material in the coating.

5. Summary

The mechanisation and automation solutions in coating by hardfacing welding lead, compared with manual or partly mechanised processes, besides improvement of the quality also to less frequently occurring inacceptable downtime. A result from the first test series is the doubling of the service life during the test period, compared with the former technology.

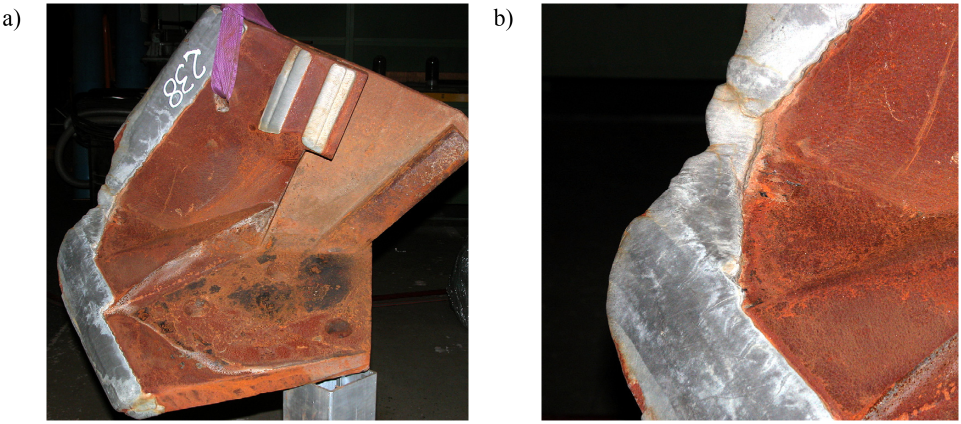

Fig. 5. Worn cutting edge 238 (left)/plasma-arc powder surface-weld

Compared with the filler wire A (FeCr22Nb7C5,2 / Type 61) the alloys *B*, *C* do, when applied in clay-containing soil using the same coating technologies, not bring about decisive advantages with regard to the total wear. The wear measurements in a field test show that type *C* tends to have the better wear behaviour; this evaluation is, however, to be verified by further tests.

The new cutting edge geometry has fulfilled the requirements made to cutting capacity and also to the reduction of the energy consumption of the conveyor system. Further optimisation of the coated area must be made with regard to the increased removal on the face and wear at the underside of the cutting edge.

The comparison of the process variations (cored filler wire and plasma-arc powder surface-welding) shows solely marginal advantages of the PTA coating with regard to the service life in the comparable period. This advantage must, however, be verified in connection with the total costs. This raises the question whether process combinations on a component may be an alternative.

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