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# Raising quality of maintenance and control of metallic structures in large-load technological machines

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**Abstract.** Active growth of coal extraction and underinvestment of coal mining in Russia lead to the fact that technical state of more than 86% of technological machines at opencast coal mines is unacceptable. One of the most significant problems is unacceptable state of supporting metallic structures of excavators and mine dump trucks. The analysis has shown that defects in these metallic structures had been accumulated for a long time. Their removal by the existing method of repair welding was not effective – the flaws reappeared in 2–6 months of technological machines' service. The authors detected the prime causes that did not allow to make a good repair welding joint. A new technology of repair welding had been tested and endorsed, and this allowed to reduce the number of welded joints' flaws by 85% without additional raising welders' qualification. As a result the number of flaws in metallic structures of the equipment had been reduced by 35 % as early as in the first year of using the new technology.

## 1. Introduction

Coal is one of the most significant resources that stabilize the situation in Russian power industry. The advantages of opencast coal mining are obvious because 70 % of the total amount of coal mined Russia-wide is extracted at opencast mines. Kuznetsk Basin (Kuzbass) is one of the largest in Russia and in the world [1] Within the last five years there is positive increase in exported coal amounts, and Kuzbass places Russia to the third place among the most significant coal exporters after Australia and Indonesia. Kuzbass coal is exported to 85 countries of the world [2]. At the same time within the last twenty-five years investment of coal industry were insignificant. Even in 2010 which was the most stable year they made about 5 % of coal sales revenue [3].

Although despite negative investment environment out-of-date technological equipment and technological devices were replaced. But this replacement was insignificant for excavator fleet and dump truck fleet. That is the reason why opencast coal mines still use life-expired technological machines. This lead to the fact that 70 % of equipment practically every year undergoes safety review performed by experts, and the technical state of more than 86 % of equipment is unacceptable.

Considering the tendencies of early 2000s which were based on total replacement of excavators produced in Russia with hydraulic excavators of foreign origin it may be said that this strategy had failed to prove its value. The advantages demonstrated by the imported equipment come to nothing by the fourth or fifth year of service. Thus introduction of imported equipment required significant current operating costs besides capital expenditures, and tough interrepair maintenance requirements caused the necessity of the whole maintenance system reconsideration. Thus in most of the cases such equipment undergoes post-warranty maintenance and requires permanent presence of a technical-



support engineer, and absence of any technical specifications and structural complexity of basic mechanisms makes impossible to repair the equipment by the enterprises' technical support services [4].

## 2. Problem description

Above mentioned highlights the need to focus the attention on the technical state of domestically produced technological machines. The results of examination of 123 equipment fleet units at AO HK SDS-Ugol (one of the three leading Russian coal mining companies) as part of annual flaw-detection survey of supporting metallic structures (mining booms, frames, dump truck bodies etc.) highlighted unacceptable technical state of the equipment (Table 1). Examinations were performed by methods of visual and dimensional testing (V&DT), ultrasonic testing (UT) and by metal magnetic memory method (MMM).

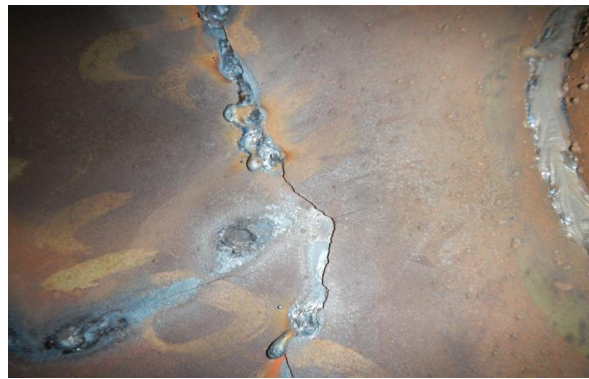
The nature of the reviewed flaws shows that the flaws had been accumulating within 3-5 years at least. Despite the fact that coal mining enterprises in Russia and particularly in Kuzbass are regulated by Federal Environmental, Industrial and Nuclear Supervision Service, and 70 % of equipment undergo annual safety review, a set of examinations necessary for equipment operational life extension are performed with formal approach to diagnostic works. They are fragmentary and are performed in minimal amount of the safety review, and this is not enough for prevention of such flaws.

**Table 1.** Results of metallic constructions examination.

Examinations	Index
Number of performed examinations including:	123
– primary	59
– removal checks	51
– expert reviews and others	13
Welded joints checked by number	9885 pcs.
the methods of V&DT, extension	3999 m
UT, MMM area	8812 m <sup>2</sup>
Total volume of sent conclusions	9118 pages
<b>Flaws</b>	
Flaws detected	5646 pcs. 2126 m
Including those found during primary examinations	4554 pcs. 1600 m
Cracks detected	2679 pcs. 523.3 m

Accumulation of flaws had been induced by the fact of their untimely removal, and thus within six months of the flaws described in Table 1 29% of flaws by number and 28% by extension was removed. The least number of flaws were removed at AO Chernigivets – 13% by number and 18% by extension. The most number – at ZAO Prokopievskiy Ugolnyi Razrez – 51% by number and 45% by extension.

More than 90 % of flaws detected in metallic structures were removed several times but reappeared. Along with this ultrasonic testing showed that in more than 98 % their was a lack of penetration in the welded joint. Figure 1 shows the photo of a typical repair welded joint from backside. As it can be seen a lack of penetration extends through the whole length of the joint.



**Figure 1.** Lack of root penetration in the repair welding joint.

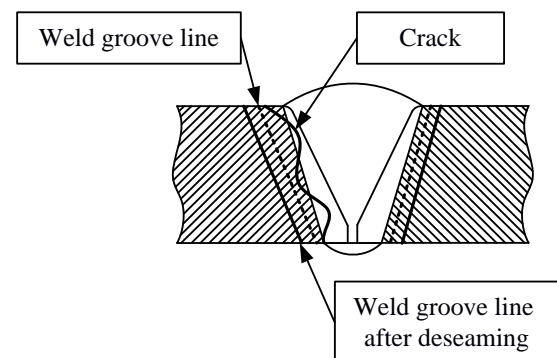
### 3. Theory

Unlike welding new metallic structures where welders' task is prepared groove of a future welded joint, the process of repair welding is organized in the way that the welders should groove and prepare the metallic structure for welding themselves. The main factors that complicate the process and do not allow to groove the welded joint in accordance with the National State Standard are [5, 6, 7]:

- curvature of the flaw and, as follows, non-linear required groove;
- different position of the flaw;
- meeting of several parallel flaws (Figure 2);
- the necessity to remove totally the welded metal and the heat-affected zone of the fractured welded joint, leading to double or triple extension of the groove area (Figure 3);
- varying thickness of the metal down the line of the flaw extension;
- absence of information about the thickness of the welded metal.



**Figure 2.** Opening of break on the mine dump truck frame.



**Figure 3.** Groove of the fractured welded connection.

All this, complicating the work of the welder who is not familiar with the groove, leads to a typical mistake – narrow groove with leaving some metal for fusion (Figure 4), and it does not allow complete root penetration with a temper bead.



**Figure 4.** Improper opening of break for making a welding joint.

#### 4. Experimental results

In order to get precise information about the causes of reappearance of the flaws on repair welded joints and to detect the reasons of lack of root penetration a special methodology allowing to model the typical working conditions for the welder making repair welded joints had been developed.

Multipass welding of metallic specimens with different thickness at their different locations was modelled. Welded joints' groove was performed by the welders themselves. Welders of the 5<sup>th</sup> and 6<sup>th</sup> categories worked with metallic specimens 16 mm thick and welders of the 3<sup>rd</sup> and 4<sup>th</sup> categories worked with specimens 6 mm thick. The criteria of the specimens' assessment met the instructions for capital repair of excavators ESh and EKG and dump trucks Belarusian Auto works 7555 и Belarusian Auto works 75131. The last additional criterion was evaluation of the welded joint for the presence of welding stress using the metal magnetic memory method.

193 welders of AO HK SDS-Ugol enterprises had participated in the experiment. The analysis of more than 80 m of welded joints in 338 welding specimens showed the results given below in Table 2.

From the Table 2 it can be seen that the dependence of the number no-go specimens' number on the welders' qualification is insignificant. On the specimens 16 mm and 6 mm thick respectively were observed: irregular ripples (91 % and 67 %), deviations of the welded joint size form the required by the National State Standard (100 % and 99 %), lack of root penetration through the full length of the welding joint (41 % and 46 %).

**Table 2.** The results of experimental welding specimen.

№	No-go criteria naming	Presence of flaws in the specimens with thickness of 16 mm, %	Presence of flaws in the specimens with thickness of 6 mm, %
1	Beatings, rough transition to the basic metal	2	28
2	Irregular ripples	91	67
3	Height of the crests excesses 1 mm	70	18
4	Ribbing along the welded joint excessing 3.0 mm	30	39
5	Height of the welded joints' step structure excesses 2.0 mm	17	15
6	Uneven welded joint filling	0	14
	Open craters	15	12
	Pores	15	23
	Air holes	7	11

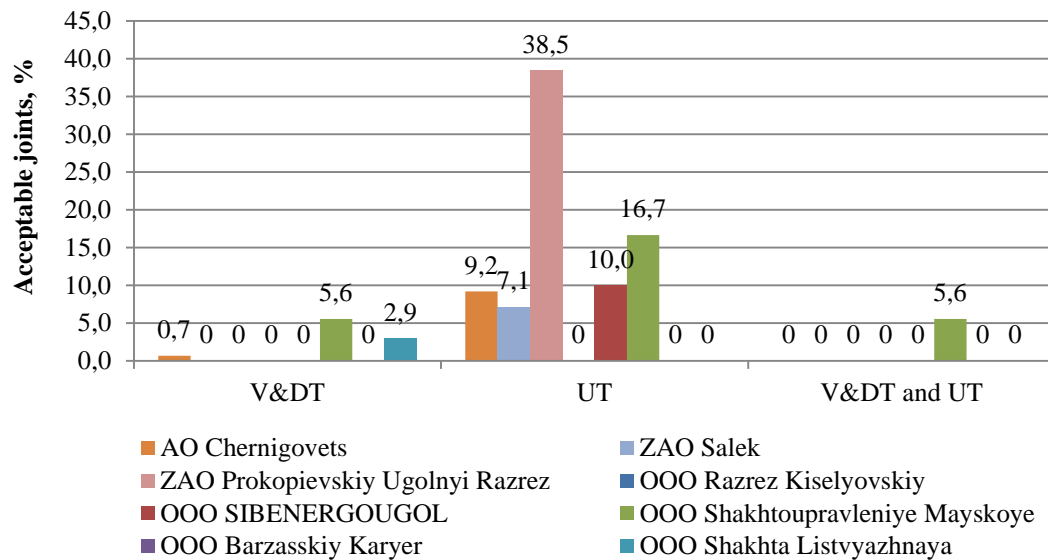


№	No-go criteria naming	Presence of flaws in the specimens with thickness of 16 mm, %	Presence of flaws in the specimens with thickness of 6 mm, %
	Burns-through of the edges	0	0
	Breaks of the welded joint	0	3
	Cracks	0	3
7	Deviations of the weld size from the National State Standard	100	99
8	Flaws with the diameter exceeding 1 mm	100	93
	Number of flaws exceeds 1 per 100 mm	100	92
	Space between the flaws less than 45 mm	100	91
9	Undercuts without correction	57	62
	Undercuts more than 0.5 mm deep	37	45
10	Specimen's edge displacement	7	18
11	Lack of root penetration through the full length	41	46
12	Bending of the specimen (more than 3 mm)	13	1
13	Welded joint's magnetic field intensity	61	0

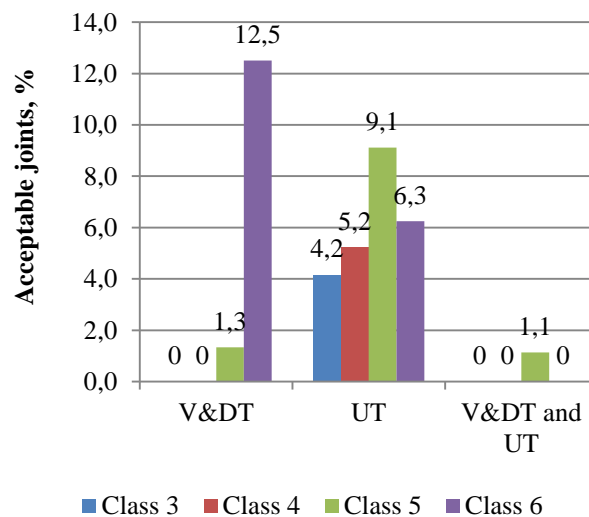
The chart presented on Figure 5 shows the results of the assessment of the welded joints quality. The welded joints were done by the workers of AO HK SDS-Ugol enterprises.

The number of specimens of the required quality according to visual and dimensional test done only by the welders of OOO Shakhtoupravleniye Mayskoye was 5.6 %. All other enterprises showed practically zero result. The specimens of ZAO Prokopievskiy Ugolnyi Razrez welders had passed visual and dimensional test and made 38.5% of their total amount. Only 5.6 % of specimens done by the welders of OOO Shakhtoupravleniye Mayskoye met the joint requirements of V&DT and UT.

The results of analysis of flaws' distributions according to the welders' categories shown on Figure 6 show that the quality of the welded joints does not depend on the welders' qualification. Thus on the one hand welders of the 6<sup>th</sup> category had expectedly more specimens meeting the norms of V&DT (11.2 % more than the welders of the 5<sup>th</sup> category), on the other hand they had less (2.8 % less) welded joints meeting the norms of UT than welders of the 5<sup>th</sup> category. And only 1.1% of specimens done by the welders of the 5<sup>th</sup> category had met the joint norms of V&DT and UT.

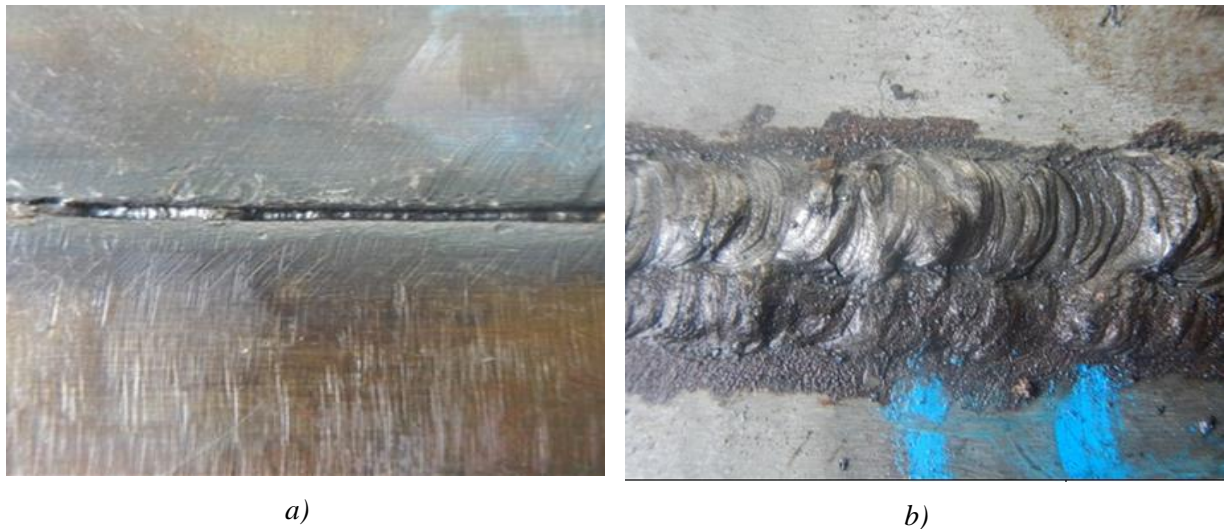


**Figure 5.** Results of the control of the specimens produced by the welders at the enterprises of AO HK SDS-Ugol.



**Figure 6.** Influence of the welder's job class on the quality of welding joints at AO HK SDS-Ugol.

The results of the experiment with welding specimens evaluation had therefore shown that there were no specimens meeting the norms set by documentary standards. The most occurring flaws were those connected with lack of root penetration (Figure 7, *a*) and form deviations of the welded joint surface (Figure 7, *b*).



**Figure 7.** Typical root defects *a)* and the surface of *b)* repair welding joint.

### 5. Discussion

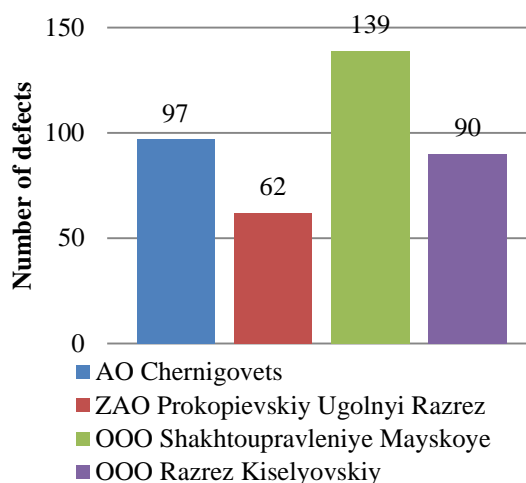
More than 91 % of flaws detected by V&DT are removed by deseaming of the weld face (if necessary with backing weld and subsequent deseaming). This method allows to remove such flaws as irregular ripples, beadings tough transition to the base metal, excessive height of the crests step structure of the welded joints and undercuts. It does not require expensive raising of welders' qualification and increases solidity of welded joints due to removal of macro- and micro acceptable flaws where welding stresses are concentrated. In the conditions of alternating strains (where welded joints usually function) it leads to the loss of their operational life due to appearing and extension of fatigue cracks. Removal of the flaws detected by UT is no less significant problem. The analysis of welded specimens' ultrasonic testing allowed to conclude that 85 % of flaws are flaws of groove (preparation for welding). They are not directly caused by the qualification of the welder making a joint, but to a greater extent they are flaws of a specialist preparing for the welding works. The solution of this problem lies in the area of repair conducting technology. Thus introduction of the method of slotted groove with installing a background plate allows to solve the problem (Figure 8).



**Figure 8.** Slotted groove of fractured welded connection with installing a background plate.



For practical approval and introduction of this technology there was an order for the whole enterprise at ZAO Prokopievskiy Ugolnyi Razrez: during the repair works on metallic structures welding joints' groove with installing a background plate is obligatory. This allowed as early as in the first year of functioning to reduce the number of detectable flaws in metallic structures of the technological machines on average by 35 % in comparison with other enterprises of AO HK SDS-Ugol (Figure 9).



**Figure 9.** Average number of defects in metallic structures detected during each examination.

According to the results of electric and gas welders' work evaluation at eight enterprises of AO HK SDS-Ugol it was found that specimens done by welders of ZAO Prokopievskiy Ugolnyi Razrez have on average 25 % less flaws in comparison with other enterprises. And the specimens with a background plate there showed no flaws.

The survey proved solidity of repair welded joints made according to the introduced technology. Thus lack of root penetration cases reduced by 85 %, and operational life of the machines raised from 2–6 months to almost unlimited. Within five years of observation 98 % of welded joints remained solid.

## 6. Summary and conclusions

1. The flaws of technological machines' metallic structures accumulate during a long period of time. Removal of these flaws by repair welding was inefficient – the period of a welded joint's life was 2–6 months. It was caused by low quality of repair and low number of removed flaws (within 6 months only 29 % of detected flaws were removed).
2. According to the results of welding specimens evaluation showing the work of 193 welders of the 3–6<sup>th</sup> categories at AO HK SDS-Ugol enterprises, no specimen of the total amount of 338 met the requirements of documentary standards.
3. The flaws detected by ultrasonic testing are in 85 % the flaws of the groove (preparation for welding works) and are not directly caused by low qualification of the welder as a specialist making the welded joint.
4. The flaws of repair welded joints (91 %) detected by visual and dimensional testing are removed by the welded joint deseaming.
5. Introduction of the method of slotted groove with installing a background plate allowed to reduce the number of lack of root penetration cases by 85 % without raising welders' qualification and extend the life of the welded joints from 2–6 months to almost unlimited. This allowed to reduce the number of equipment metallic structures' flaws by 35 % as early as in the first year of new technology introduction.

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