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Article

The influence of positioning deposited beads direction to resistance on grind wear plates' abrasive wear

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Abstract: The article presents the results of the study of the significance of influence of positioning deposited beads towards direction of abrasive movement, to resistance on grind wear plates HARDPLATE 100S' abrasive wear. The study on relevance of influence was conducted by using completely randomized design. The range of study has covered testing the metal-material abrasive wear resistance, macroscopic and microscopic metallographic examination and hardness tests.

Keywords: wear plate; hardfacing; abrasion; chromium cast iron; coatings

Introduction

Existing wear processes limit the operational life of machine parts and equipment. In industry the most common type of wear is abrasive wear (abrasion). It is estimated that it can be responsible for over 60% of costs resulting from tribological wear [1÷3].

Welding technologies enable applying layers and coatings resistant to abrasion. For example, surfacing is used in the production of plates with wear-resistant padding weld (wear-resistant plates), which allow even a few-fold reduction in the wear intensity of machine elements [1,2,4÷13].

Commonly, these plates are manufactured by surfacing using wire with a powder core of a layer with specific properties on a structural steel substrate. With the use of additional material that provides the required structure, padding welds are made, which have a high resistance to wear occurring during operation, e.g. abrasion, erosion, abrasion at impact loads and corrosion. The most often padding welds of wear-resistant plates correspond to the composition of high-alloy chromium cast irons, hence they are mainly used to counter abrasion under conditions of intense metal-mineral friction. The wide use of wear-resistant plates also results from the possibility of their forming through plastic processing (rolling, bending) and the possibility of assembly through separable (e.g. screw) and inseparable (e.g. welded) connections. In order to ensure adequate dimensional accuracy, objects made of plates with wear-resistant padding welds are shaped by abrasive machining, e.g. by grinding wheels (Fig. 1) [1,6,7,13].

Fig. 1. View of support plates (made from grind wear plates) guide systems in ring-ball mills [13]

In the technical documentation of the parts of equipment for which the use of plates with ground wear-resistant padding weld is foreseen, the designers determine the direction of beads laid on the surfaced layer or leave the manufacturer the freedom of choice. The qualitative data given in the literature boils down to recommendations regarding the direction of beads of padding welds' beads in relation to the direction of abrasive motion [12]. However, no literature information was found containing quantitative data on abrasion resistance of ground padding welds depending on the position of stitches in relation to the direction of displacement of abrasive elements. Therefore, an attempt was made to determine the influence of the direction of motion of abrasive particles in relation to the direction of the padding weld's beads placement on the abrasion resistance of ground wear-resistant plates.

The paper presents the results of tests for resistance to abrasive wear of the metal-mineral type for different values of angles of setting the beads' direction of plates with ground wear-resistant padding weld HARD-PLATE 100S 6+4 produced by Welding Alloys in relation to the flow direction of the abradant. The significance of the impact was determined by conducting studies using a randomized complete statistical program. The scope of the research also included macro and microscopic metallographic examinations as well as measurement of the hardness of the welded layer.

Materials

HARDPLATE 100S 6+4 wear-resistant plates are manufactured by automatic surfacing with powder self-shielding wire to ensure the alloy of high-alloy Fe15 chromium cast iron according to PN-EN 14700:2014-06, string beads with a layer thickness of approx. 4.0 mm on a non-alloy steel substrate S235JR according to PN-EN 10025-2:2007 with a thickness of 6.0 mm. These panels are recommended for protecting surfaces exposed to intensive metal-mineral abrasion at moderate impact loads [13].

The course of research

Abrasion resistance testing

The research aimed at determining the significance of the impact of the direction of bead placement in relation to the abradant's movement direction on abrasion resistance of ground wear-resistant plates HARDPLATE 100S was carried out using a complete randomized static program designed to assess the significance of the influence of one input factor on the output factor [14]. The significance level of influence α = 0.05 was assumed. The following angle values were adopted between the direction of motion of the abrasive elements and the direction of surfacing of the beads: 0°, 30°, 45°, 60°, 90°. For each angle value, 6 abrasion resistance tests of the metal-mineral type were assumed. According to the assumptions and the concept of randomization, 30 sheets of HARDPLATE 100S 6 4 plates were marked with natural numbers from 1 to 30 based on their production date – from the latest to the earliest produced. Then a sequence of random numbers was obtained using a computer random number generator [15]. Using the generated sequence of numbers, the wear-resistant plates were randomly assigned to the appropriate values of the tested factor. The measurement scheme of a static randomized complete program taking into account the assumptions and assignment is presented in figure 2 [14]. The individual 75 x 25 mm samples were cut from the individual wear-resistant plates to ensure that the angle between the longer side of the sample and the direction of the bead placement was 0°, 30°, 45°, 60° or 90° (Fig. 3). The location of cracks in the surfaced layer of the samples was accidental. The cut samples were subjected to circumferential disk grinding. In the grinding process, the direction of the feed rate of the tangential table was parallel to the direction of bead placement.

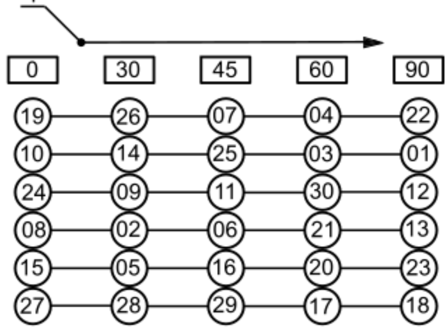


Fig. 2. Scheme of measurements of completely randomized design; 1 – angle between direction of abrasive movement and positioning of deposited beads

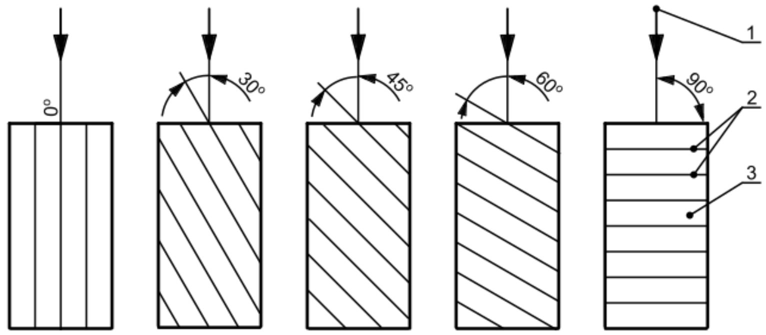


Fig. 3. Positioning of deposited beads of grinding wear plates samples towards direction of abrasive movement; 1 – direction of abrasive movement, 2 – positioning of deposited beads, 3 – grinding wear plates samples

Testing of abrasion resistance of the metal-mineral abrasion of wear-resistant plates was carried out on the basis of ASTM G 65, procedure A. During the test, the abrasive flow rate was 302 g/min. The samples were loaded with a constant force of 130 N. The friction wheel rotated at 200 rpm and the frictional path was 4309 m. Fire-dried quartz sand with spherical grain and granulation of 100÷300 μm was used as the abrasive sand. In order to determine the resistance to abrasive wear of padding welds, the loss of mass and density of the padding welds were measured. Samples before and after the study were weighed on laboratory scales with an accuracy of 0.0001 g. The average density of the wear-resistant plate used in the study was determined using a laboratory scale, based on three measurements of the density of the surfaced layer of one sample, weighed in air and liquid. The volume loss was determined using the mass loss values of the sample and the average value of the measured padding weld's density in accordance with formula (1). The results obtained are shown in table I.

$$U_o = \frac{U_m}{\rho} \cdot 1000 \qquad (1)$$

where:
U_o – volume loss, mm^3;
U_m – mass loss, g;
ρ – density, g/cm^3.

Table I. Results of the metal-material abrasive wear resistance test of grinding wear plates samples

The angle between the direction of movement of abrasive particles and the direction of beads placement, °	**Loss of the padding weld's volume, mm³* (loss of the padding weld's mass, g)**						
	1	**2**	**3**	**4**	**5**	**6**	**Average for individual levels**
0	19.6682 (0.1432)	20.6571 (0.1504)	18,2947 (0,1332)	22,0305 (0,1604)	20,7669 (0,1512)	19,2561 (0,1402)	20,1123 (0,1464)
30	20.8906 (0.1521)	22.8409 (0.1663)	19,5583 (0,1424)	21,4125 (0,1559)	20,3137 (0,1479)	23,2941 (0,1696)	21,3850 (0,1557)
45	20.0527 (0.1460)	20.7532 (0.1511)	20,3824 (0,1484)	18,3222 (0,1334)	22,0168 (0,1603)	20,2176 (0,1472)	20,2908 (0,1477)
60	20.7257 (0.1509)	20.7669 (0.1512)	20,0390 (0,1459)	22,5250 (0,1640)	19,0776 (0,1389)	20,6296 (0,1502)	20,6273 (0,1502)
90	22.1542 (0.1613)	20.1764 (0.1469)	22,7722 (0,1658)	19,8193 (0,1443)	22,4975 (0,1638)	19,3660 (0,1410)	21,1309 (0,1539)
			For all results				20.7093 (0.1508)

* loss of the padding weld's volume was determined according to the formula (1).
Measured density of the padding weld of wear-resistant plate HARDPLATE 100S 6+4 is 7,2808 g/cm^3

According to the implementation scheme of the randomized complete statistical program, an analysis table of variance was created (Table II)

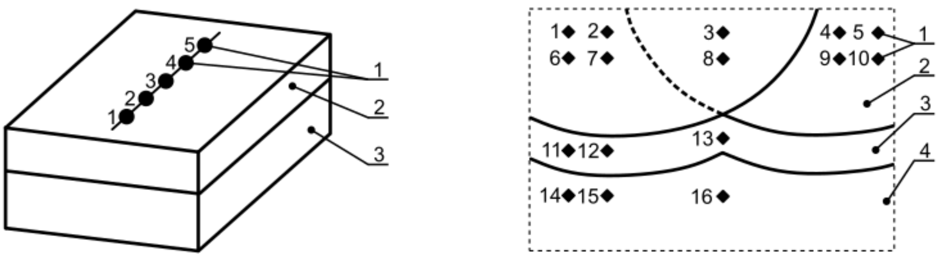
Table II. Analysis of variance table

Name	Sum of squares S	Number of degrees of freedom f	Average square s²	Value of the test F
Between systems	$S_{MU} = \sum_{i=1}^{K} r_i \bar{y}_i^2 - N\bar{y}^2 = 7.03599$	$f_{MU} = K - 1 = 4$	$s_{MU}^2 = \frac{S_{MU}}{K-1} = 1.7590$	$F = \frac{S_{MU}^2}{S_{WU}^2} = 0.9993$
Inside the system	$S_{WU} = \sum_{i=1}^{K}\sum_{j=1}^{r_i} y_{ij}^2 - \sum_{i=1}^{r_i} r_i \bar{y}_i^2 = 44.00543$	$f_{WU} = N - K = 25$	$s_{WU}^2 = \frac{S_{WU}}{N-K} = 1.7602$	–
Rest	$S_R = \sum_{i=1}^{K}\sum_{j=1}^{r_i} y_{ij}^2 - N\bar{y}^2 = 51.04142$	$f_R = N - 1 = 29$	–	–

where:
r_i – the number of measurements of the input factor at a given level; N – total number of measurements of the input factor;
$\bar{y}_i$ – average of measurement results; $\bar{y}$ – average of results from all measurements;
y_{ij} – the value of the j-th resultative factor at the i level; K – number of variability levels of the tested factor

Hardness measurements

Measurements of hardness of layers of surfaced samples from ground wear-resistant plates were carried out on the surface of the padding weld's face using the Rockwell method (Fig. 4a) and for 2 samples on the cross-sectional area of the plate in the area of the overlap of the padding weld beads, heat affected zone and basic material using the Vickers method (Fig. 4b). The results of hardness measurements obtained are presented in table III, IV and V.

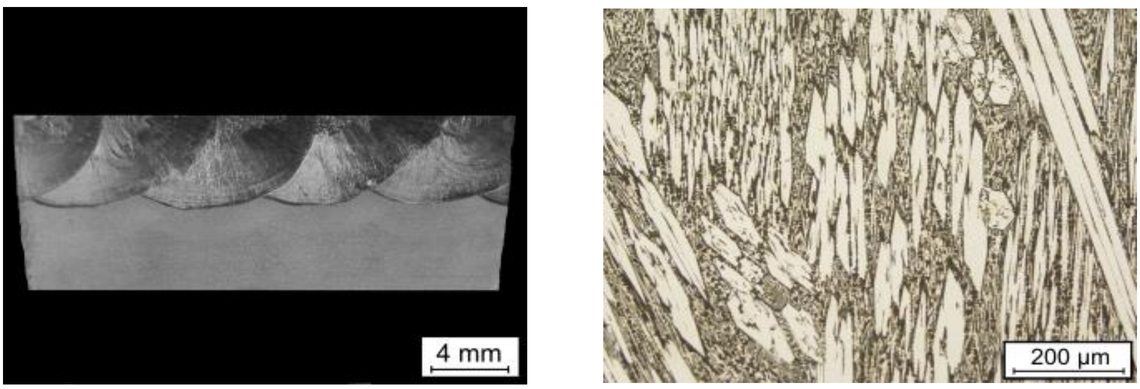


(a) (b)

Fig. 4. Hardness tests points distribution: a) on the face of overlay weld of grind wear plates; 1 – hardness test points, 2 – grinding hardfacing deposit, 3 – base material, b) on the surface of grinding wear plates' cross section; 1 – hardness test points, 2 – grinding hardfacing deposit, 3 – heat affected zone, 4 – base material

Metallographic examinations

In order to determine the quality of the surfaced layer, micro- and macroscopic metallographic examinations were performed. Metallographic examination of the sample with the number 19, whose angle between the longer side of the sample and the direction of beads placement is 0°, was carried out on transverse metallographic specimen using a light microscope. The results of macroscopic metallographic examinations are presented in figure 5a, and metallographic microscopic findings in figure 5b.



(a) (b)

Fig. 5. a) The macrostructure of grinding wear plate HARDPLATE 100S' 6+4; b) and microstructure of hardfacing deposit of this plate

Table III. Results of HRC hardness measurements on the face of hardfacing deposit samples of grinding wear plates

Sample number	Angle between the longer side of the sample and the direction of beads placement, °	Hardness measurement point *					Average value of the hardness of the sample, HRC
		1	2	3	4	5	
19	0	59.5	61.0	62.5	61.5	59.5	60.8
10	0	59.0	60.0	62.5	61.0	60.5	60.6
24	0	60.5	61.0	61.5	61.5	59.5	60.8
08	0	59.5	60.0	60.5	61.0	61.0	60.4
15	0	58.5	59.5	61.0	60.0	61.0	60.0
27	0	62.5	62.5	60.5	59.5	60.0	61.0
26	30	58.5	60.0	60.5	60.5	60.0	59.9
14	30	60.5	60.0	61.5	60.5	61.0	60.7
09	30	60.5	59.0	62.0	61.0	61.0	60.7
02	30	59.5	61.5	60.5	60.0	60.5	60.4
05	30	59.5	61.0	62.5	62.0	60.5	61.1
28	30	59.5	60.0	60.5	62.0	61.0	60.6
07	45	61.5	62.0	59.0	60.5	60.0	60.6
25	45	60.5	61.5	61.0	62.0	60.5	61.1
11	45	60.0	59.0	60.5	61.0	60.5	60.2
06	45	60.5	59.5	61.0	61.0	58.5	60.1
16	45	60.5	60.5	61.0	60.5	60.0	60.5
29	45	60.5	61.0	60.5	60.0	59.0	60.2
04	60	59.0	61.5	60.5	62.0	60.5	60.7
03	60	61.0	62.0	60.0	60.0	59.5	60.5
30	60	60.5	61.0	62.0	60.5	59.5	60.7
21	60	60.0	58.5	60.5	60.5	60.0	59.9
20	60	61.5	61.5	59.5	60.0	59.5	60.4
17	60	59.5	60.0	61.0	60.0	61.0	60.3
22	90	58.5	59.0	59.5	61.0	60.5	59.7
01	90	62.0	60.5	60.0	61.0	59.0	60.5
12	90	60.0	60.5	60.5	60.5	59.0	60.1
13	90	59.5	61.5	62.0	60.0	60.0	60.6
23	90	61.0	61.5	60.0	58.5	59.9	60.2
18	90	60.0	62.0	62.0	59.5	60.0	60.7

* marking of measurement points in accordance with figure 4a

Table IV. Results of HV30 hardness measurements on cross section of hardfacing deposit samples of grinding wear plates

Sample number	Angle between the longer side of the sample and the direction of beads placement, °	Hardness measurement point *									
		1	2	3	4	5	6	7	8	9	10
19	0	804	711	761	814	754	825	709	729	791	803
10	0	747	746	703	784	697	728	688	747	759	812

* marking of measurement points in accordance with figure 4b

Table V. Results of HV10 hardness measurements on cross section of heat affected zone and base material samples of grinding wear plates

Sample number	Angle between the longer side of the sample and the direction of beads placement, °	Hardness measurement point *					
		11	12	13	14	15	16
19	0	174	185	167	150	163	152
10	0	177	170	161	148	154	141

* marking of measurement points in accordance with figure 4b

Analysis of research results

The conducted tests of abrasion resistance of ground wear-resistant plates HARDPLATE 100S showed that regardless of the direction of bead placement in relation to the direction of movement of abradant, the surfaced layer is characterized by high resistance to abrasion. The average loss of padding weld's volume determined based on ASTM G 65 for particular values of bead angles is in the range of 20.1123÷÷21.3850 mm^3. The significance of the impact study was conducted using a randomized complete statistical program. The value of the F test calculated on the basis of statistical analysis of test results (Table II) is less than the critical value F0.05; 4; F Fischer-Snedecor F test [14]. It authorizes us to state that for the adopted level of significance and the calculated number of degrees of freedom, the direction of bead placement in relation to the direction of movement of abrasive particles does not significantly affect the abrasion resistance of the metal-mineral type of plates with ground wear-resistant padding weld.

The hardness measurements carried out on the face of the padding weld of ground wear-resistant plates show high hardness of the surfaced layers and high repeatability of results irrespective of the direction of bead placement with respect to the longer side of the sample. The average hardness values of individual samples are in the range of 59.7÷61.1 HRC, while the gap is 4.0 HRC. There was no deterioration of the padding weld's hardness in the bead joints zone. The hardness measured on the cross-sectional area of the padding weld is within 688÷825 HV30, and in the area of the beads' overlap 703÷761 HV30. The heat affected zone has a hardness of 161÷185 HV10, while the base material 141÷163 HV10. In both cases, the measured hardness does not exceed the maximum permissible hardness of 380 HV10 according to PN--EN ISO 15614-7:2016-12 for steel from material group 1.

The metallographic tests carried out did not indicate the occurrence of welding defects in the surface layer of the plate with wear-resistant padding weld. The surfaced layer is properly connected to the base material and the penetration has a regular circular shape. On the basis of microscopic examination, it can be concluded that the padding weld of the wear-resistant plate probably has a structure composed of large chromium carbides in the austenitic matrix.

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