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CLASSIFICATION AND CHARACTERISTIC OF DEFECTS OF DEPOSITED LAYERS ACCORDING TO THE INTERNATIONAL STANDARD ISO 6520-1:2007

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The review of defects of deposited layers on the basis of their classification system according to the International standard ISO 6520-1:2007 and its analogue GOST R ISO 6520-1:2012 was carried out. According to these standards, the welding (surfacing) defects are divided into six main groups with the corresponding three-digit number: cracks (100–106), cavities (200–203), solid inclusions (300–304), lacks of fusion and lacks of penetration (400–403), deviation from shape and sizes (500–521) and other defects (600–618), i.e. the defects, which are not included into the first five groups. Within each group, the defects are divided into the corresponding subgroups with four-digit numbers. The nature of defects of deposited layers was analyzed from the point of view of their admissibility and inadmissibility in the process of operation of deposited parts. 9 Ref., 17 Figures.

Keywords: *surfacing, deposited metal, defects of deposited layers, classification of defects, admissible defects, inadmissible defects, quality evaluation*

The reliability, serviceability, efficiency of manufacture and safety of the subsequent service of deposited parts depend mainly on the quality of deposited metal and the presence or absence of different defects in it. The origin of these defects is associated with metallurgical, hydrodynamic and thermal processes occurring in surfacing. Thus, their appearance depends mainly on chemical composition of the base and deposited metals, methods, technology and technique of surfacing.

A detailed analysis of defects of the deposited metal, the causes of their formation and methods of their prevention are given in the work [1]. The aim of this publication is the characteristic of different groups of defects of deposited layers, given in the standards [2, 3].

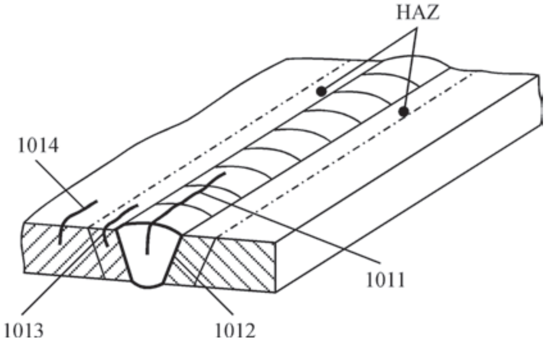

Figure 1. Weld with longitudinal cracks: 1011 — in weld metal; 1012 — in fusion zone; 1013 — in HAZ metal; 1014 — in base metal [2, 3]

In welding (surfacing) practice the concept of defect as discontinuity or other flaw is widespread, which is admissible (if its parameters do not exceed the limit value according to the corresponding standard or technical specifications) or inadmissible. In this paper the traditional definition of a defect as a discontinuity in a weld (deposited metal) or deviation from the required shape and sizes of weld (deposited bead), accepted in the standard ISO 6520-1:2007 [2] and its analogue GOST R ISO 6520-1:2012 [3] is used.

According to the standards [2, 3], the welding (surfacing) defects are divided into six main groups having the corresponding three-digit number: cracks (100–106), cavities (200–203), solid inclusions (300–304), lacks of fusions and lacks of penetration (400–403), deviation from shape and sizes (500–521) and other defects (600–618), i.e., the defects which are not included into the first five groups. Within each group, the defects are divided into subgroups. For example, the number 101 denotes longitudinal cracks, 102 — transverse, 103 — radial cracks, etc. In their turn, the defects in subgroups are divided into separate types with four-digit numbers.

Cracks (100-106). The cracks are macro- or microscopic discontinuities which have the character of a notch. In the standards [2, 3], the cracks are char-

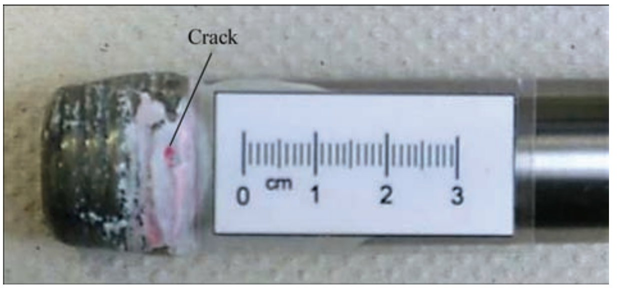

Figure 2. Crack in crater (104) of closing bead of deposited layer performed by arc surfacing using flux-cored wire in inert gas (process 132, deposited metal of the group CO_2 [4–6])

acterized mainly from the geometric point of view. As an example, Figure 1 shows the numerical indices of longitudinal cracks, which are located in different zones of a weld [2, 3].

The cracks, like most other defects, can be admissible and inadmissible. For the process of surfacing, the admissibility of cracks in the deposited metal is determined primarily by the conditions of service of parts.

The cracks are inadmissible in the case when they can cause damage of the part or impossibility of its further service. Among such parts there are plungers of hydraulic presses, mill rolls, parts of stop valves, valves of internal combustion engines, etc.

The examples of inadmissible defects are cracks in the crater (104) of the closing bead of deposited layer of the reinforced surface of the stop valve part (Figure 2); microcracks in the deposited layer (1001) of cast iron parts due to violation of the surfacing technology (Figure 3); longitudinal cracks in the deposited layer (1011), which are the result of using a poor-quality wire during surfacing (Figure 4) or violation of surfacing mode (Figure 5). The used processes and consumables of surfacing are marked in accordance with the requirements [4–6].

Inadmissible are also the transverse cracks in the HAZ metal (1023) in case of surfacing the broach of

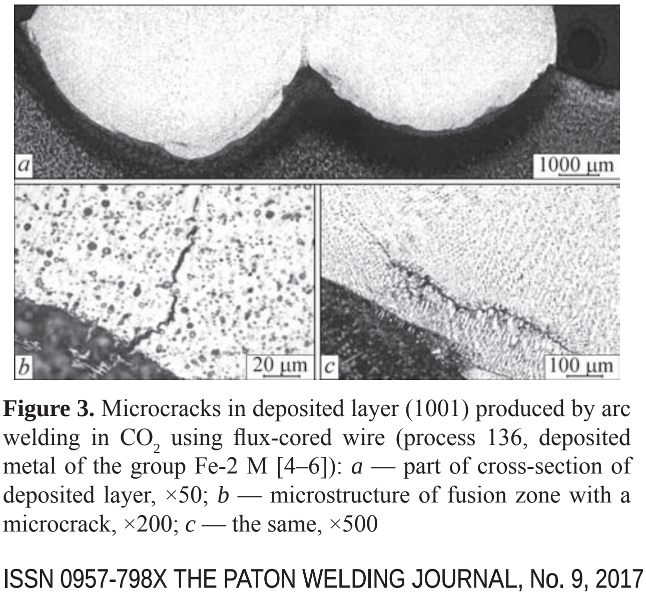

Figure 3. Microcracks in deposited layer (1001) produced by arc welding in CO_2 using flux-cored wire (process 136, deposited metal of the group Fe-2 M [4–6]): *a* — part of cross-section of deposited layer, ×50; *b* — microstructure of fusion zone with a microcrack, ×200; *c* — the same, ×500

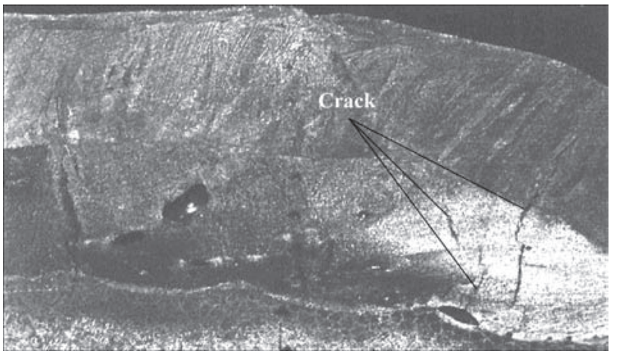

Figure 4. Longitudinal cracks in the deposited layer (1011) produced by arc surfacing using solid wire in active gas (process 135, deposited metal of the Fe1 group [4–6])

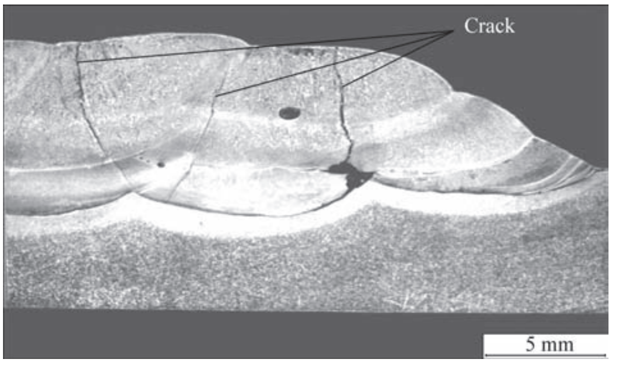

Figure 5. Longitudinal cracks in deposited layer (1011), produced by arc surfacing using flux-cored wire in inert gas (process 132, deposited metal of the CO_2 group [4–6])

hardened steel 38Kh2MYuA. The cracks have a character of tear in the HAZ metal (Figure 6, *a*) or spalling of the deposited layer (Figure 6, *b*). The cause for their appearance can be violation of the surfacing technology.

For some parts, the cracks have no such a decisive significance, especially if they do not transfer into the base metal or are not oriented parallel to the fusion surface and do not lead to spallings of the deposit-

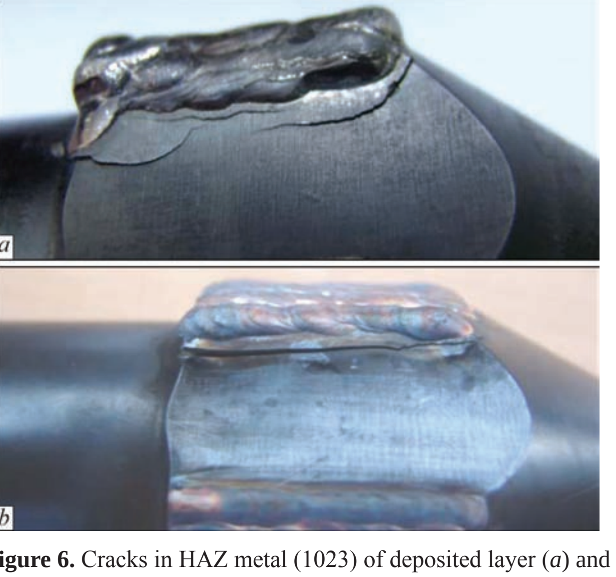

Figure 6. Cracks in HAZ metal (1023) of deposited layer (*a*) and the spalling (1023) of deposited layer (*b*) of steel 38Kh2MYuA

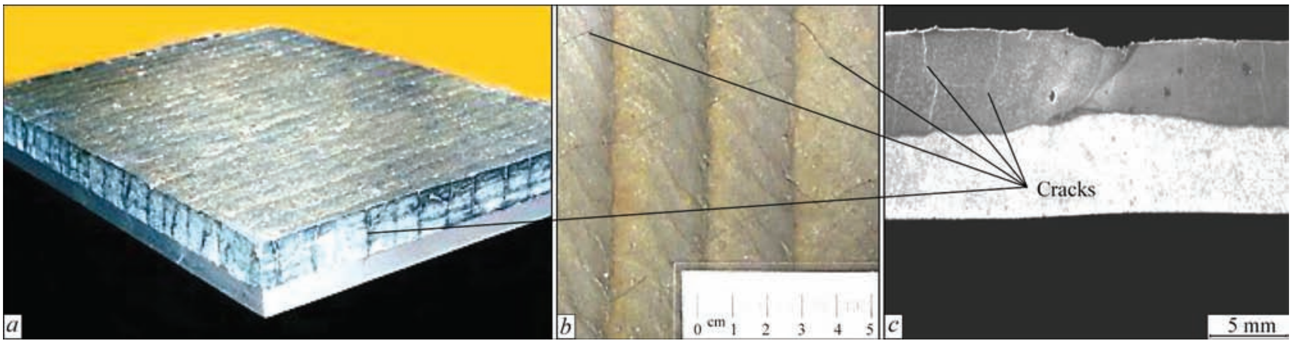

Figure 7. Admissible longitudinal (1011) and transverse (1021) cracks in wear-resistant layer of bimetal sheets, deposited by high-chromium cast iron (process 114, deposited metal of the group Fe14 [4–6]): *a* — deposited bimetal sheet with cracks; *b* — cracks in separate deposited beads; *c* — macrostructure of deposited bimetal sheet

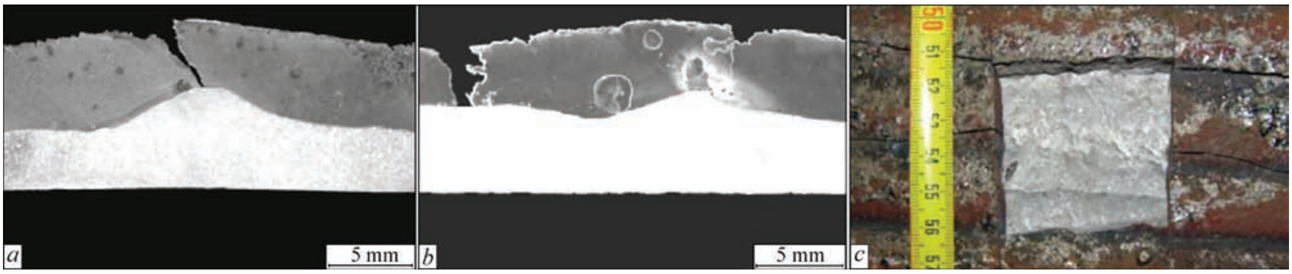

Figure 8. Inadmissible cracks (1011) (*a*, *b*) and separation (1023) (*c*) of wear-resistant layer of sheets deposited by high-chromium cast iron [4]

ed metal. They include cones and bowls of charging equipment of blast furnaces, different chutes for transportation of abrasive materials, hoppers and other parts that operate under conditions of different types of intensive abrasive wear. These parts are deposited using the materials of groups Fe13–Fe16 and Fe20 [5, 6]. The examples of admissible longitudinal (1011) and transverse (1021) cracks in the deposited layer of wear-resistant bimetal sheets are shown in Figure 7.

In some cases, cracks in the operating layer, deposited by high-chromium cast iron, can lead to inadmissible spalling and separation of the deposited layer (1011 and 1023) (Figure 8).

It should be noted that in the standards [2, 3], an alphabetical (of two letters) classification according to the types of welding cracks is given as a reference appendix. All cracks are denoted by the capital Latin letter «E». Accordingly, hot cracks have the designation «Ea»; crystallization cracks — «Eb»; subsolidus cracks — «Ec»; cold cracks — «Ef»; cracks, caused by hydrogen — «Ei»; lamellar cracks — «Ej», etc.

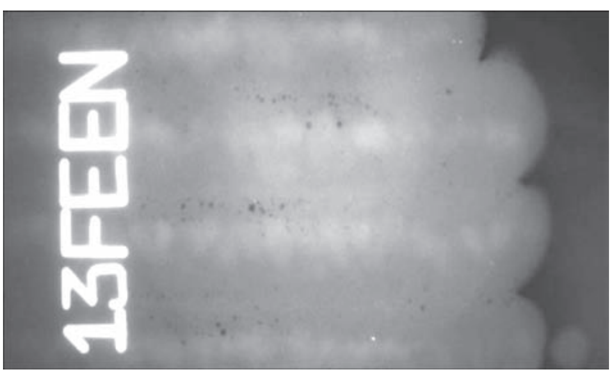

Figure 9. Pore clusters (2013) in the layer deposited by MIG method using solid bronze wire [7]

Cavities (200–203). The cavities of different shapes in welds (in the deposited layer) are classified as follows [2, 3]: 201 — gas cavities formed by a delayed gas evolved during crystallization; 202 — shrinkage cavities, i.e. the cavities formed as a result of shrinkage during crystallization; 203 — microshrinkage (shrinkage cavity), visible exclusively under the microscope.

At the same time the gas pores, which are most often found in the welds, are understood as gas cavities of almost spherical shape, which are denoted by the index 2011.

In most cases, the pores in the deposited layer can be detected using radiographic or ultrasonic testing. In Figure 9 [7] a radiogram of the layer with pore clusters is presented, deposited by the MIG method using a solid bronze wire (2013).

The pores, similar to cracks, can be admissible or inadmissible defect in the deposited layer. An example of admissible surface pores (2017) in the deposited layer of wear-resistant bimetal sheets is shown in Figure 10.

In other cases, for example, in the layer deposited on critical cast iron parts, which operate under the conditions of high contact pressure and friction of metal against metal, the inner gas pores (2011) are not admitted (Figure 11).

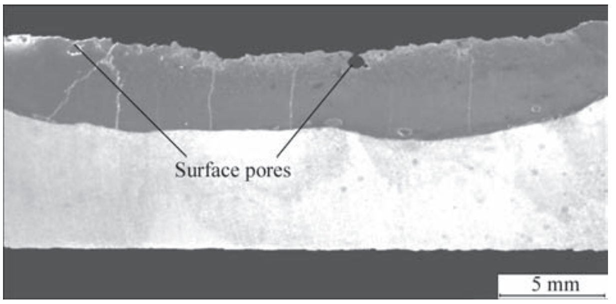

Figure 10. Admissible surface pores (2017) in wear-resistant layer of bimetal sheets deposited by high-chromium cast iron (process 114, deposited metal of the Fe14 group [4–6])

Solid inclusions (300–304). The solid inclusions in the deposited metal are foreign substances of a small volume of nonmetallic or metallic origin [2, 3]. They include slag (301), flux (302), oxide (303) and metal (304) inclusions among. Among the metal inclusions there are inclusions of tungsten (3041), copper (3042) or other metals (3043).

The slag inclusions can form in the welds (deposited metal) during manual arc welding or surfacing using stick electrodes, during welding or surfacing using self-shielding flux-cored wires (Figure 12, *a*) and during automatic submerged arc surfacing (Figure 12, *b*).

Lacks of fusion and lack of penetration (400–402). The lacks of fusion (401) is the absence of a joint between the base and deposited metal or between separate layers (beads). Due to their shape, which is mostly flat, the lacks of fusion can act as stress concentrators, significantly reducing the fatigue life of deposited parts [9]. The examples of interlayer (4011) and interbead (4012) lacks of fusion formed during mechanized surfacing of the inner surface of a position pipe applying MAG method are shown in Figure 13. The cause of appearance of these defects is the violations of surfacing technology.

Lacks of fusion (4011) can appear when the modes of other surfacing methods are violated, as for example, in plasma-powder (Figure 14, *a*) and laser-powder (Figure 14, *b*) surfacing.

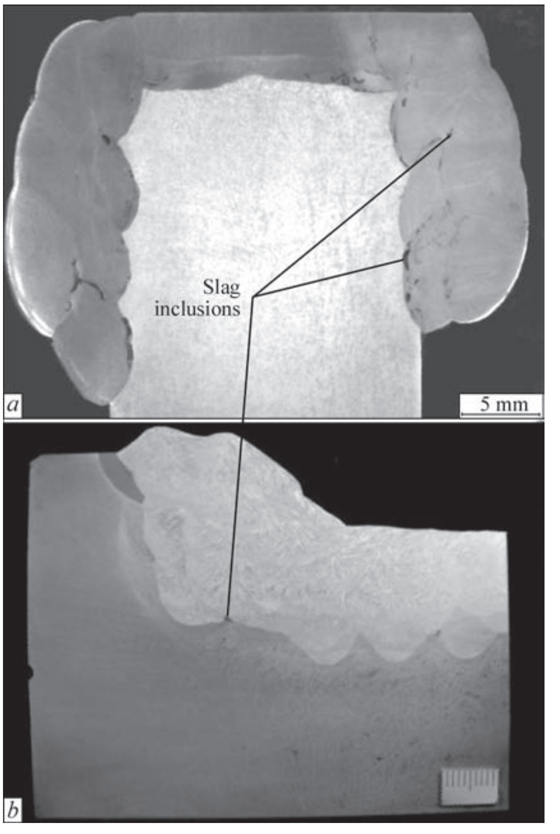

Figure 12. Macrostructure of cross-section of deposited mandrel (*a*) [4] and crane wheel (*b*) with slag inclusions (301) [8]

Lack of penetration (402), according to the standards [2, 3] is the difference between the actual and nominal penetration depth. During surfacing these defects occur rather rare.

Deviation from shape and size (500–521). This is the most numerous group of defects which, in particular, includes undercuts (501), excess of penetra-

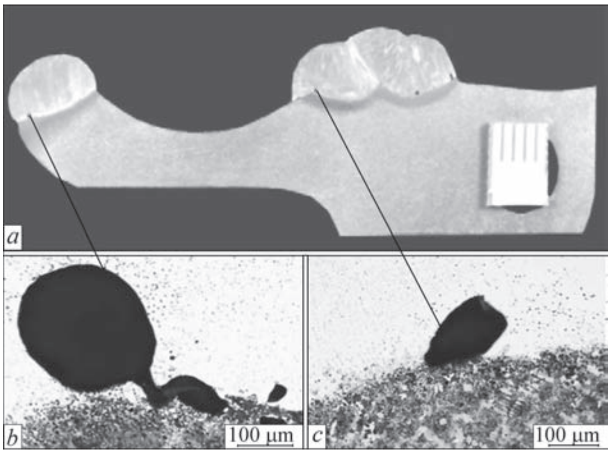

Figure 11. Inadmissible inner gas pores (2011) in the layer deposited on critical cast iron parts: *a* — macrostructure of deposited part; *b, c* — gas pores in deposited metal at the fusion boundary

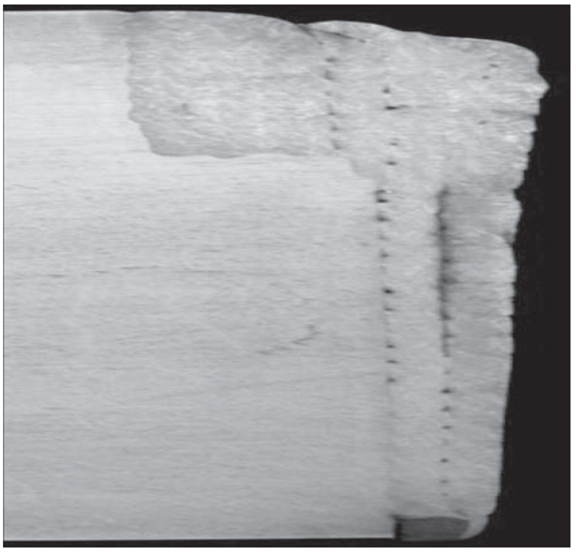

Figure 13. Interlayer (4011) and interbead (4012) lacks of fusion in surfacing of inner surface of 170 mm diameter position pipe applying MAG method

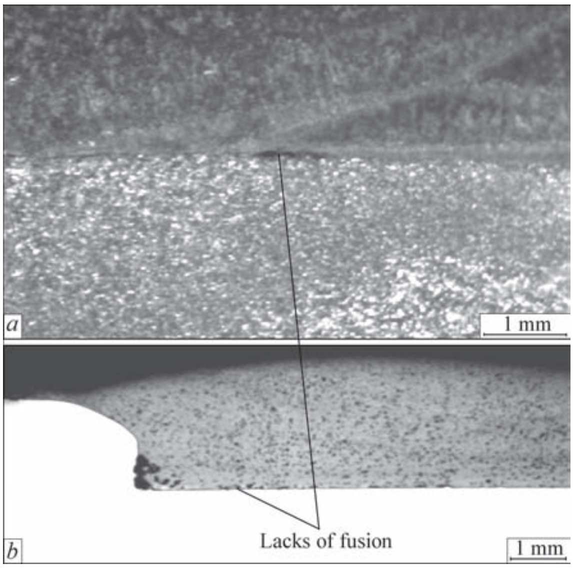

Figure 14. Lacks of fusion at the interface of joint of base and deposited metals (4011) in plasma-powder (*a*) and laser-powder surfacing (*b*) [4]

tion (504), irregular weld profile (505), lapping (506), linear displacements (507), burnouts (510), lack of groove filling (511), non-uniform width of weld (513), uneven weld surface (514), poor re-exciting of the arc (517), distortion (520), irregular weld sizes (of deposited bead) (521) [2, 3].

For surfacing the most characteristic of them are:

● undercut (501) — deepening at the interface of bead in the base metal or in the previous deposited bead;

● excess of penetration (504) and burnouts (510), which can appear during surfacing of thin-walled parts in case of violation of surfacing technology;

● non-uniformity of the reinforcement of the deposited bead along the length or insufficient overlapping of beads across the width of the deposited layer, related to the violation of surfacing technology (514);

● poor reexciting of the arc (517) — local unevenness of the surface at the site of welding (surfacing) renewal;

● distortion (520) — deviation of dimensions of a part from those specified by the drawing, arisen from welding (surfacing) deformations;

● irregular sizes of deposited bead (521) due to violation of surfacing mode, magnetic blowing or low skill of a surfacing operator.

During surfacing of flat or cylindrical surfaces of a large area, quite often such a defect (514) occurs as a non-uniform reinforcement of deposited bead along the length or insufficient overlapping of beads across the width of the deposited layer. After mechanical treatment, this leads to appearance of grooves of different depth and extension (Figures 15, 16) on the surface of the deposited layer.

Figure 17 shows the appearance of beads deposited by two stainless steel strips of 120 mm width. Depending on the place of current supply, the character of formation of deposited beads is changed. If the current supply is carried out at a considerable distance from the axis of the bead (Figure 17, *a, b*), then as a result of arising effect of magnetic blowing, the formation of deposited bead is deteriorated (defect 521).

Other defects (600–618). The rest ones include all the defects, which are not mentioned in the groups

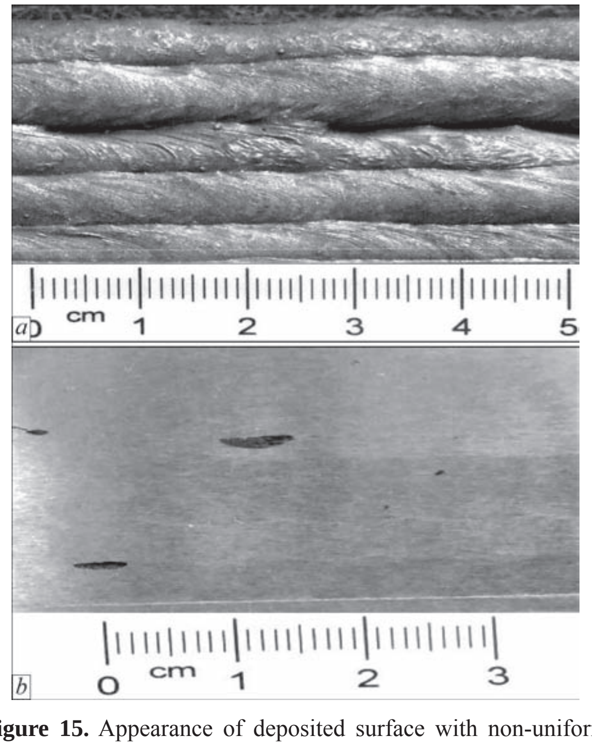

Figure 15. Appearance of deposited surface with non-uniform reinforcement of deposited beads and insufficient overlapping of adjacent beads (514) directly after surfacing (*a*) and after mechanical treatment (*b*) [4]

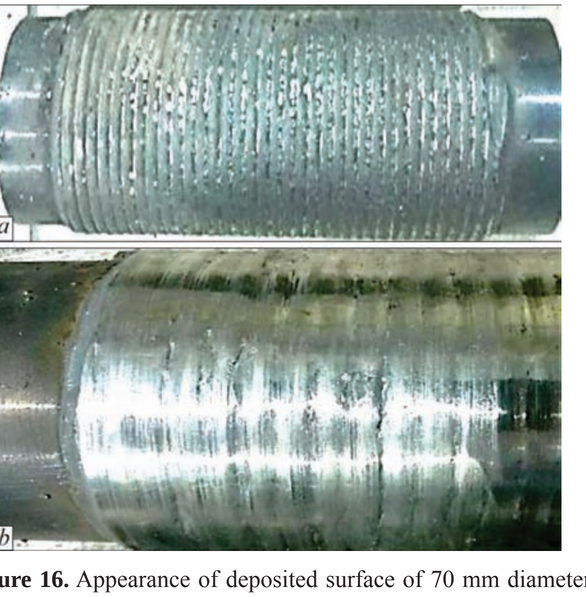

Figure 16. Appearance of deposited surface of 70 mm diameter bead with non-uniform reinforcement of deposited beads and insufficient overlapping of adjacent beads (514) directly after surfacing (*a*) and after mechanical treatment (*b*)

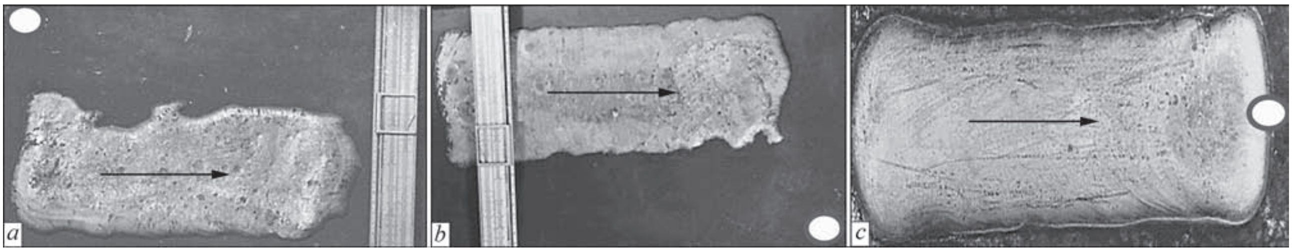

Figure 17. Violation of bead shape (521), depending on place of current supply to the workpiece and effect of magnetic blowing: *a* — current supply on the left side of weld axis; *b* — current supply on the right side of weld axis; *c* — current supply along the weld axis (o — location of current supply, → — direction of surfacing)

1–5. Among them, the most significant for surfacing are: arc burn (601); spatters of metal (602); tempering colors (610); slag remnants (615). In detail:

● 601 — local damage of the surface of base metal adjacent to deposited layer, which occurred as a result of accidental ignition of the arc;

● 602 — drops of deposited metal, which are formed during surfacing process and are welded-on to the surface of the solidified deposited layer or near-weld zone of base metal;

● 610 — thin colored oxide film on the surface in the welding (surfacing) zone, for example, in welding of stainless steel, the appearance of which is caused by heating during welding (surfacing) and/or insufficient protection, for example, during welding (surfacing) of titanium;

● 615 — slag, not completely removed from the surface of weld or deposited metal.

The carried out review of different groups of defects of deposited layers confirmed the possibility of their classification and characteristics according to the standard ISO 6520-1:2007 and its analog GOST R ISO 6520-1:2012 Welding and related processes. Classification of geometry defects and continuities in metallic materials. Part 1. Fusion welding.

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