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EFFECT OF IMPACT AND BENDING LOADS ON AN ENAMEL COATING AS A FUNCTION OF THE COATING DEPOSITION CONDITIONS

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The processes occurring under impact fracture of a primed enamel coating on steel are examined. The effect of the method used to prepare the metal, the thickness of the metal, and the type and thickness of the enamel on the impact resistance of an enamel coating on a flat surface are evaluated. The regularities in the impact fracture of an enamel coating are investigated for 'internal' and 'external' fractures.

Key words: single-layer direct-on and ground-coat enameling, impact resistance of enamel coatings, spider defect.

A significant drawback of protective enamel coatings, which prevents their wide use in industry, is coating fracture under impact. For this reason the impact resistance of enamel coatings is one of the most important operating properties. An evaluation of the effect of the metal preparation method, metal thickness, and type and thickness of the enamel coating on the impact resistance of an enamel coating on a flat surface is the objective of the present work.

METHODS OF STUDY

Flat plates coated on both sides by enamel (direct-on boron, danburite No. 1, and boron-free No. 2 ground coat) with thickness 0.09 – 0.22 mm were tested using an apparatus for determining the Vickers impact strength. The impacted surface was considered to be the external surface and the opposite surface internal. The tests of all enamel samples were performed according to GOST R 51164–98 [1] at room temperature after the sample was soaked for at least 3 h at temperature 40 ± 3°C and then subjected to thermal cycling (10 cycles at temperature from +80 to –80°C). The appearance of the first crack (cleavage) on the external side and a 'spider' on the internal side were recorded.

The strength of the enamel coating is characterized by the impact energy corresponding to the appearance of the first cleavage on the external surface and a 'spider' on the internal surface. This disrupts the continuity of the enamel coating and results in corrosion of the metal at this location.

The bending tests were conducted by monitoring the coating by catching and recording acoustic pulses generated by the cracking of the enamel coating. Enameled cast-iron samples were subjected to bending to deflection 4 mm with the supports separated by 150 mm.

RESULTS AND DISCUSSION

The tests showed that the methods used to prepare the metal being enameled, viz., rough firing followed by etching in sulfuric acid (with and without the addition of an inhibitor), degreasing in alkaline solutions (with and without nickel plating), and sand blasting — fracture of the enamel coating, have little effect on the impact fracture energy of an enamel coating.

For metal thickness 0.63 mm, coating thickness 0.22 mm, and diameter 40 mm of the ring used on the external surface, the first cleavages appeared at impact energy 6.0 – 6.2 N · m and the spider on the internal surface appeared at 1.9 – 2.1 N · m (Fig. 1).

In addition, the method used to work the metal affects the character of the fracture and the form of the cleavage of the enamel coating [2]. In the presence of nickel plating the adhesion of the coating to the metal increases sharply and samples with stronger adhesion give cleavages with a large area on the external side and small area on the internal side; in addition, coating discontinuity occurs inside the ground-coat layer without exposure of the metal [3].

As adhesion degrades, the cleavage area becomes shrinks significantly on the external side and expands on the internal side; in addition, coating fracture is partial or com-

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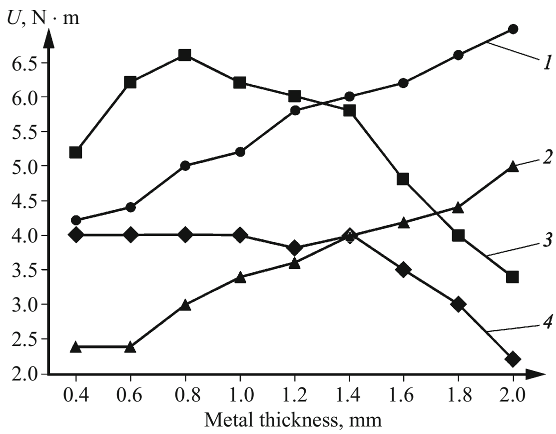

Fig. 1. Impact resistance of coatings versus the metal thickness: *1*) appearance of the first cleavage on the internal side; *2*) appearance of a 'spider' on the internal side; *3*) appearance of the first cleavage on the external side; *4*) appearance of the first marker due to an impact on the external side.

plete along the ground-coat – metal boundary. This is explained by the fact that because of separation from the metal with poor adhesion the enamel coating on the external side deforms on a smaller area than with good adhesion.

It is also necessary to take account of the fact that the impact of the striker on the plate being tested, which has a cushioning effect, aside from fracturing the enamel coating at the location of contact with the ball, produces elastic deformation of the plate between the supports and residual indentation deformation of the plate at the impact location. The fracture of the enamel as a result of the impact is shown schematically in Fig. 2. If the impact is weak, very small cracks, delimited by the region *OA*, appear at the location of contact with the ball.

As the force of the impact increases, the enamel coating fractures along the surface *AC* as a result of the deformation of the plate and cleavage of the sections *OAC* occurs. The enamel column within the region *OA* usually remains on the plate at the center of the damaged sections. The coating fractures on the internal side as a result of the deformation of the plate: a 'spider' appears, followed by a 'star wheel' and cleavage of sections of the coating.

If the metal is thin, the deformation of the plate is so strong that a 'spider' appears on the internal side even if the impact force is less than the value causing the first fracture on the external side. Initially, an increase in the thickness of the metal has a favorable effect on the impact resistance of the external enamel coating, since the impact force giving rise to the first cleavage increases. For larger metal thickness, the cushioning decreases sharply and the impact force sufficient to obtain the first cleavage on the external surface decreases. In addition, in this case the character of the cleavage also changes as a result not of the deformation of the plate but rather the impact of the striker — the cleavage area decreases sharply.

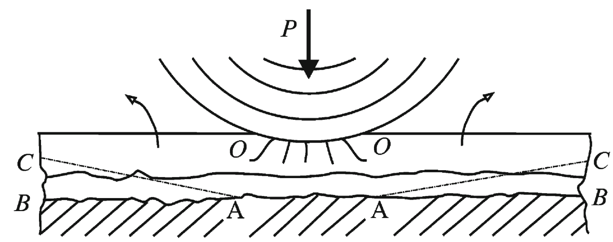

Fig. 2. Diagram of the fracture of the coating on the external side: *1*) metal; *2*) ground-coat enamel; *3*) cover-coat enamel.

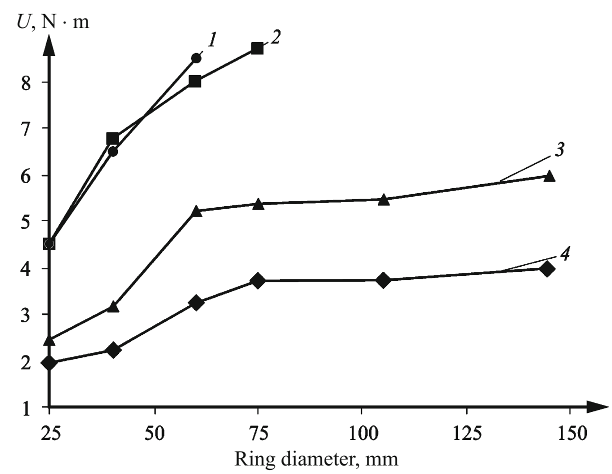

Fig. 3. The impact energy versus the diameter of the support ring; the energy of an impact causing fracture of the enamel on the external side: *1*) on metal 1.18 mm; *2*) on metal 0.63 mm; *3*) on metal 1.18 mm; *4*) on metal 0.63 mm.

The dependence of the impact resistance on the diameter of the support column for the 'internal' and 'external' fractures is presented in Fig. 3. The impact energy giving rise to the cleavage on the external side increases more rapidly with increasing diameter of the ring; this is due to a decrease of the stiffness and increase of the cushioning effect of the plate.

Another kind of load giving rise to fracture of the enamel layer during use is bending, which is especially significant for cast-iron articles. In Table 1 an oscillographic trace is compared with a visual count of the number of cracks in samples of coatings deposited on cast iron.

As one can see from the data presented, there is no absolute correspondence between the number of cracks and

TABLE 1. Comparison of a Trace and Visual Count

Enamel type	Coating thickness, mm	Number of pulses in the oscillogram	Number of cracks (visual count)
Ground-coat No. 1	0.22	23	23
Ground-coat No. 2	0.12	16	14
Direct-on enamel	0.09	9	8

cleavages on the one hand and the number of pulses recorded on the other. Apparently, in individual cases the appearance of an acoustic pulse is associated not with the appearance of a new crack (or cleavage) but rather with the expansion or deepening of a previously formed crack.

CONCLUSIONS

This research shows that the impact resistance of enameled articles is practically independent of the preparation method, but the character of the fractures depends on the adhesion of the coating to the metal. If adhesion is weak, the cleavage of the enamel under impact occurs on the internal surface of the article along the ground-coat – metal boundary. The ground coat of thickness 0.1 mm preserves the dielectric continuity under voltage 1 kV after an impact with energy 3.8 – 4.0 N · m.

As the metal thickness increases, the internal surface of the enamel coating fractures under a weaker impact force and the external surface under a stronger impact force. As the metal and enamel coating increase in thickness, the deformation of the plates under the impact decreases, and for this reason the impact energy giving rise to fracture of the coating on the internal surface increases.

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