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REPAIR OF SCREWS OF EXTRUDERS AND AUTOMATIC MOLDING MACHINES BY PTA SURFACING

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The peculiarities of formation of a bead on narrow tip of screw flight in PTA surfacing were investigated. It is shown how a shape of deposited bead depends on its section and main technological parameters of surfacing, i.e. arc current, surfacing speed and PTA torch zenith displacement. The nomograms for selection of surfacing mode parameters were proposed. Equipment and consumables used for surfacing are also described. Repair of screws of extruders and automatic molding machines using PTA surfacing allows repairing these parts as well as 3–5 times increasing their service life in comparison with new nitrated screws. 11 Ref., 13 Figures.

Keywords: *PTA surfacing, screws of extruders and automatic molding machines, narrow tip, bead formation, surfacing parameters, equipment and consumables*

In process of operation the screws of extruders and automatic molding machines are subjected to intensive wear-out, in particular, during processing of composite plastics with fillers having abrasive effects. Wear of these parts takes place mainly on the flight tips, which resulted in increase of working gap between the screw and cylinder and, as a consequence, drop of productivity of screw extruder in whole. Regardless nitration, which is used to raise wear resistance, their service life in a series of cases does not exceed 6–8 months. These parts are complex on design (Figure 1) and expensive, therefore, repair and increase of their service life is a very relevant problem.

The most efficient method for repairing the screws is surfacing of a thin layer (1–2 mm) of wear- and corrosion resistant alloy on flight tip. The best for this is a method of PTA surfacing (PTAS), which due to its technological peculiarities allows providing excellent formation of deposited bead at minimum melting of flight tip [1–5].

Surfacing on flight tip of screw is sufficiently difficult technological problem due to design peculiarities of these parts. First of all, this is a large relationship of length to diameter reaching in modern machines 30, and the varying sizes of flights on part length, namely width and height. The surfacing is also complicated by wide range of screws, in which diameter can be changed from 20 to 300 mm, length from 600 to 6000 mm and width and height of flights from 3 to 30 mm.

Earlier E.O. Paton Electric Welding Institute and then Plasma-Master Ltd with participation of the author of this paper have carried the large complex work on optimizing the PTAS process of screws with development of special surfacing alloys and equipment. Surfacing in repair of screws shall be performed directly on flight tip, i.e. on the surface with limited width and large curvature. Under these conditions it is very difficult to provide set size and shape of bead, in particular, in surfacing of parts of small diameter (20–40 mm), having flight width only 3–4 mm. In order to solve this problem it was necessary to investigate the peculiarities of bead formation on narrow substrate and set the relationship between its shape and main technological parameters of the process of plasma surfacing.

Formation of bead on flight tip of screw. Cross-section profile of deposited bead is formed under effect of many factors, namely surface tension of weld pool met-

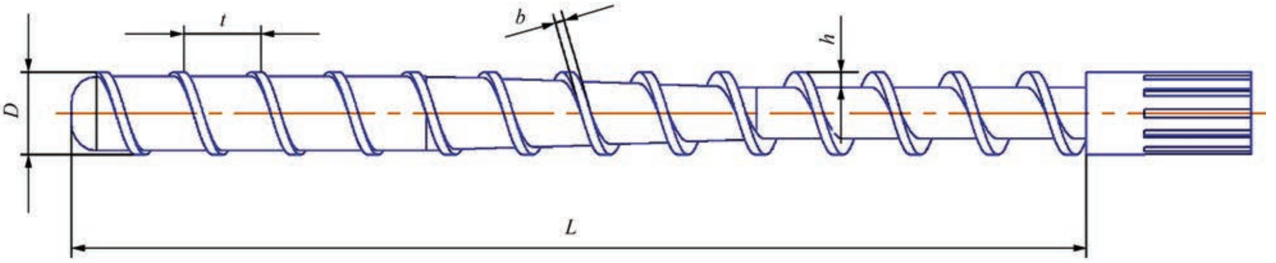

Figure 1. Typical screw of extruder for processing of polymers

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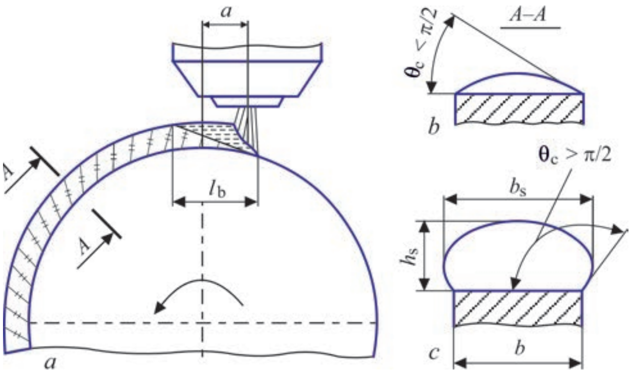

Figure 2. Scheme of surfacing on tip of screw flight (*a*) and shape of deposited beads at small (*b*) and close to optimum (*c*) cross-section area

al, gravity force, arc pressure, etc. [6–8]. The main peculiarity of formation lies in the fact that bead width in its bottom always equals to a flight width (Figure 2).

In this case the most important parameter, which determines a bead shape, is its fullness, i.e. cross-section area S_s. Rise of S_s provokes increase of height h_s as well as change of coefficient of bead shape K ($K = b_s/h_s$) and angle of bead contact with substrate θ_c (Figure 3).

Bead shape becomes more favorable from point of view of machining allowances ($b_s > b_b$), but there is rise of danger of dripping of weld pool metal in the process of surfacing. Therefore, in surfacing with free formation of bead section its height, respectively, can be increased only to some level depending on width of flight screw bead and metal capillary constant of the weld pool metal.

Figure 4 shows the optimum for deposited metal of 220Kh18FM2N3 [9, 10] type values of $S_{s.o}$ and $h_{s.o}$ at which favorable formation of beads is provided ($\theta_c > 90°$; $b_s > b$) and there is no dripping of weld pool liquid metal in side directions. However, bead cross-section at this flight width ambiguously determines its shape. The latter in many respects depends on technological parameters of the process, i.e. arc current I_a, surfacing rate V_s, arc zenith displacement *a* (Figure 1, *a*), etc.

Base metal penetration in PTA surfacing on the optimum modes is insignificant [11], therefore cross-section area of beads is proportional to value of relationship of powder feed G_f to surfacing rate V_s. Keeping this relationship constant it is possible to obtain deposited beads with set S_s at different deposition rate of surfacing process. However, increase of filler

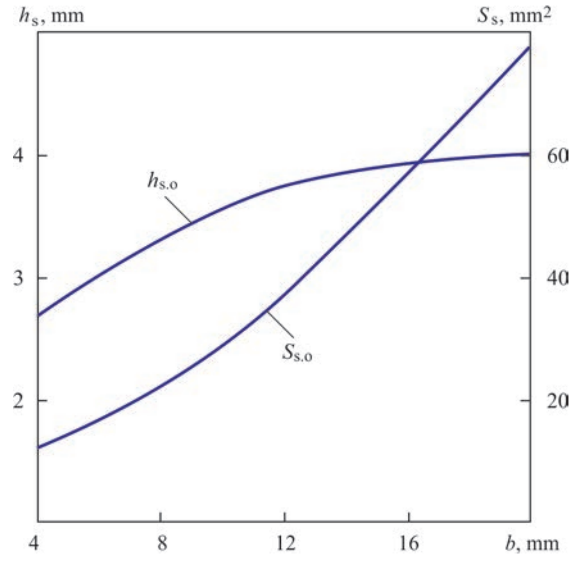

Figure 4. Optimum cross-section areas $S_{s.o}$ and height $h_{s.o}$ of deposited bead for different width of flight tip *b*

powder feeding requires increase of arc current, that, in turn, results in rise of weld pool length (Figure 5).

As can be seen from Figure 5, length of weld pool is particularly large at small width of flight (up to 8 mm), when surfacing is performed without transverse oscillations of PTA torch on relatively high currents. If length of the weld pool reaches critical value L_{cr} for this diameter of part *D*, the process of surfacing is disturbed because of dripping of liquid metal (Figure 6), which can not be prevented due to arc zenith displacement. Based on our data $L_{cr} = (0.22–0.26)/D$.

Surfacing of flights of more than 8 mm width is performed with transverse oscillations of PTA torch thanks to which the weld pool has smaller length at similar currents (see Figure 5). Besides, in these cases the deposited parts, as a rule, have larger diameter, therefore in practice the critical length of the pool is usually not achieved.

In turn, the weld pool length considerably depends on flight height that is related with change of conditions of heat sink into the part. Increase of flight height provokes also rise of pool length, however, at that lower current is necessary (Figure 7).

The higher the flight, the more obvious pool elongation is. In real parts the flight height is usually changed from 2 to 3 mm (dosing zone) up to 15–20 mm (filling zone). Under these conditions the length of weld pool at similar surfacing rate in one

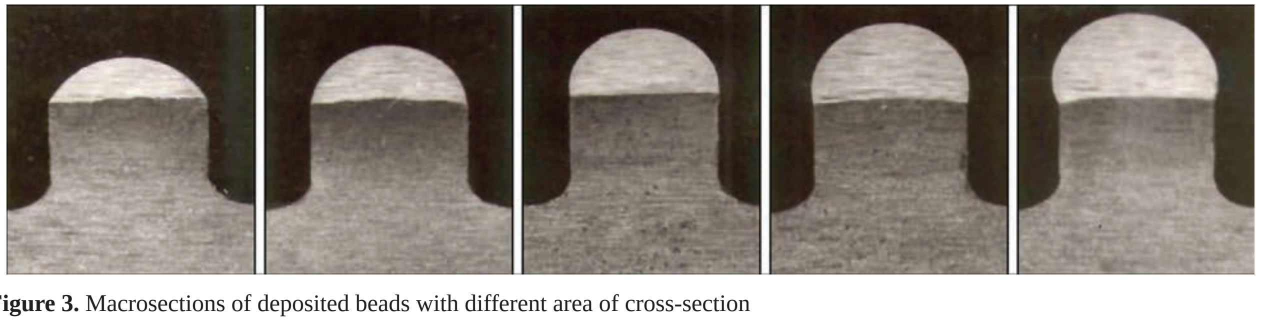

Figure 3. Macrosections of deposited beads with different area of cross-section

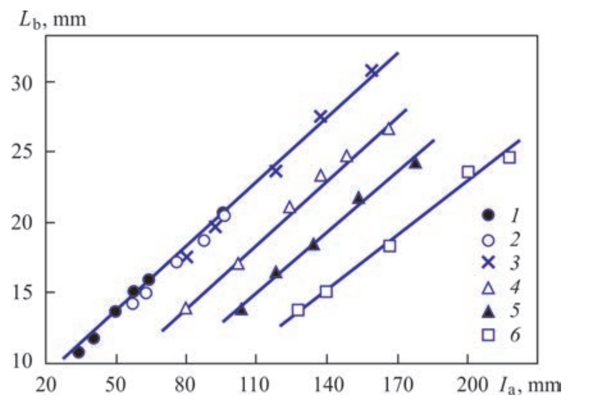

Figure 5. Dependence of weld pool length L_p on arc current I_a in tip width b [6]: *1* — b = 4; *2* — 5; *3* — 7; *4* — 10; *5* — 15; *6* — 20 mm

place of the screw can be less critical, and in the other, vice versa, more critical.

In addition to length of a weld pool selection of the optimum parameters of surfacing mode requires also considering the shape of bead cross-section, which determines machining allowances. It to larger extent depends on surfacing rate and PTA torch zenith displacement. Effect of these parameters on bead shape with similar area of cross-section is shown on macrosections (Figure 8).

As can be seen (Figure 8, *a*) rise of V_s at constant displacement of PTA torch from zenith *a* deteriorates the bead shapes. They became more convex and provoke decrease of side overhanging of the deposited metal. It takes place due to elongation of tail part of the weld pool since rise of V_s obligatory requires increase of welding current.

Increase of PTA torch zenith displacement to the side opposite to part rotation vice versa improves the bead shape (Figure 8, *b*). They became wider and flatter since they are formed under conditions of higher arc pressure. However, the displacement can be increased only to some extent, which does not violate the equilibrium between hydrostatic pressure of liquid metal of weld pool and arc pressure. Based on our data the displacement should not exceed $2/3L_b$. In practice, it is approximately (0.10–0.12)*D*. In the other case it will be difficult to hold the pool on the flight surface and liquid metal start dripping. This parameter is particularly important in surfacing of the small diameter parts of 40–60 mm. Zenith displacement can be increased to 0.2*D* at rise of part diameter and width of flight, when surfacing is carried out with PTA torch oscillations.

Thus, effect on the surfacing process of arc current, surfacing rate and PTA torch zenith displacement, the three parameters which are tightly connected with each other, becomes apparent through change of size and shape of the weld pool.

Carried investigations show that there is comparatively narrow area of surfacing modes for each dimension type of the part, which provides favorable

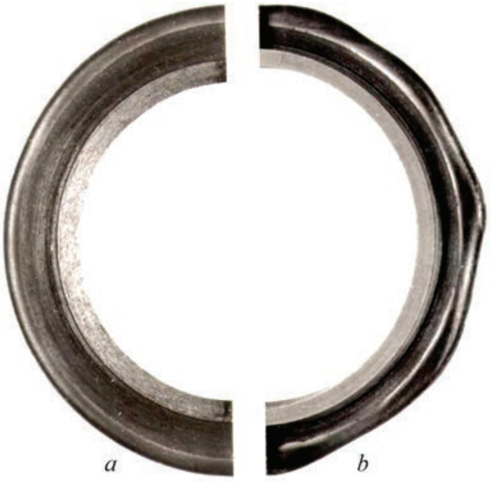

Figure 6. Appearance of deposited beads at pool length less than critical (*a*) and more (*b*); *d* = 90 mm; *b* = 7 mm

bead shape and absence of liquid metal dripping. The results of investigations of effect of surfacing technological parameters on bead formation were processed using a mathematical statistics method. The calculation considers not only the modes of surfacing, which provided the optimum section of deposited bead, its good formation and minimum penetration of the base metal. Number of points for observation made 78. Obtained data were used for plotting nomograms for selection of surfacing modes convenient for practical application (Figure 9).

For example, they show a sequence of selection of a mode for surfacing of 90 mm diameter screw with flight tip width 8 mm. The surfacing parameters, namely powder feed and PTA torch zenith displacement are constant along the whole screw length, and arc current at transfer from filling zone to dosing zone shall increase from I_1 to I_2 in accordance with decrease of flight height h_1 to h_2.

As it was already mentioned, at flight width more than 8 mm the surfacing is carried out with PTA torch oscillations. In this case amplitude A and oscillation frequency *f* are determined on formulae:

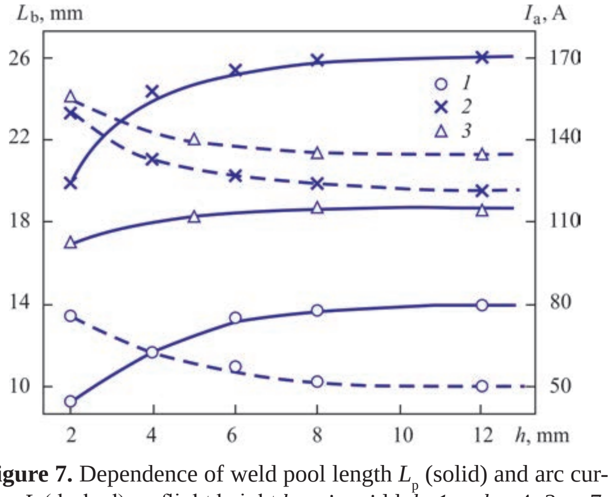

Figure 7. Dependence of weld pool length L_p (solid) and arc current I_a (dashed) on flight height *h* at tip width *b*: *1* — *b* = 4; *2* — 7; *3* — 15 mm

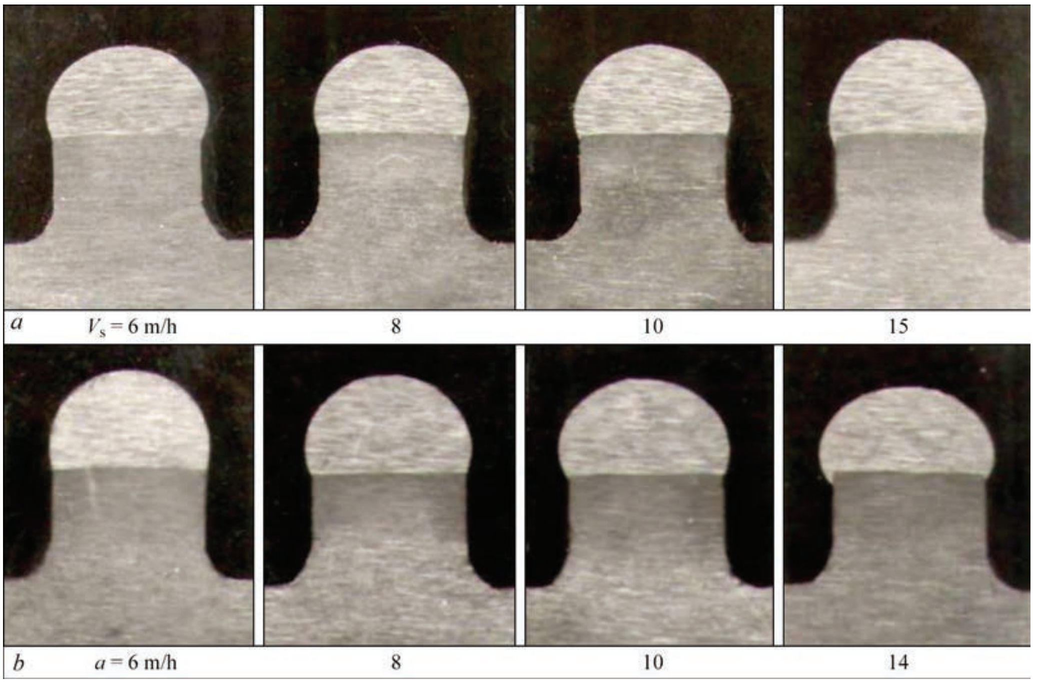

Figure 8. Macrosections of beads of similar section deposited on tips of flights of 7 mm width with different rates (*a*) (zenith displacement 11 mm) and different displacement from zenith (*b*) (surfacing rate 8 m/h)

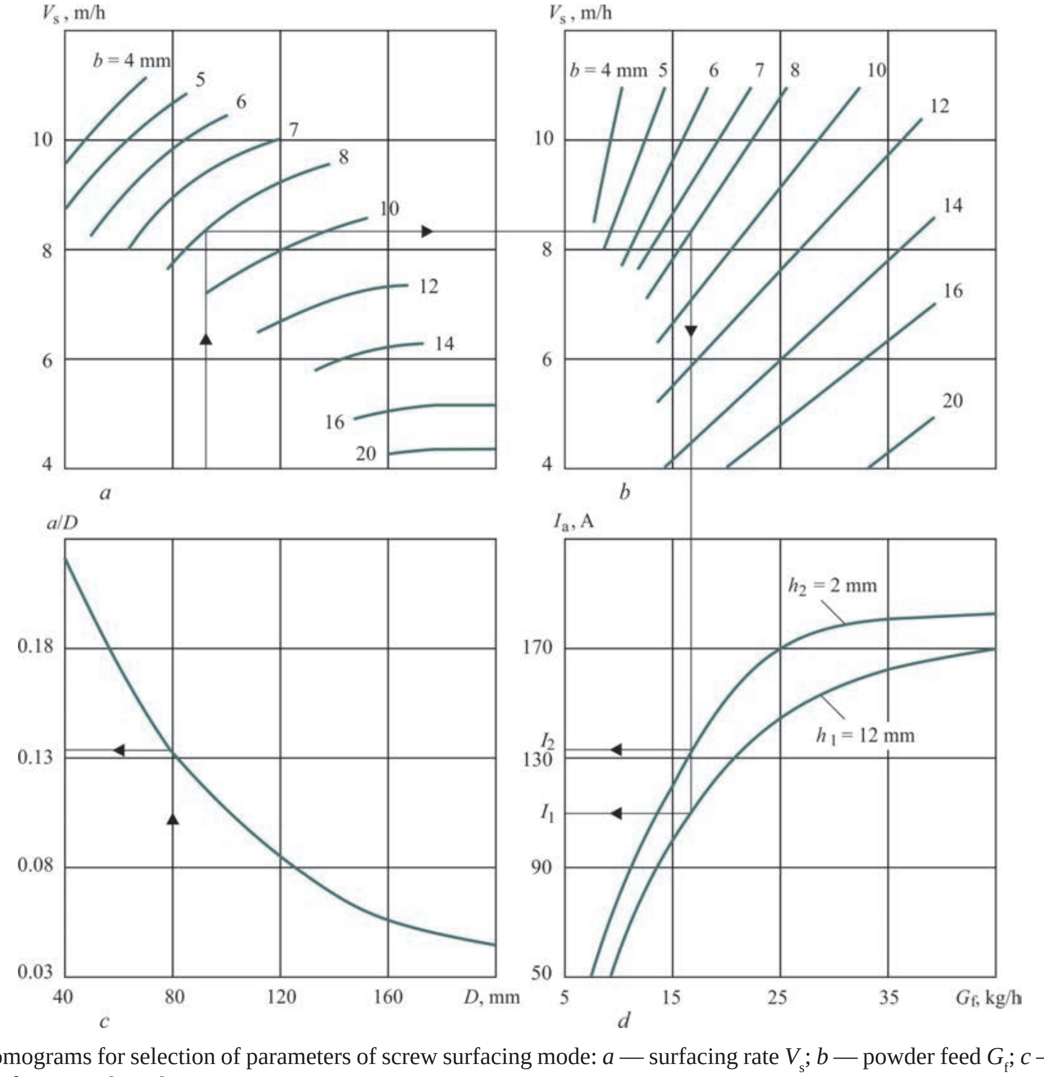

Figure 9. Nomograms for selection of parameters of screw surfacing mode: *a* — surfacing rate V_s; *b* — powder feed G_f; *c* — PTA torch displacement from zenith *a*; *d* — arc current I_a

$$A = \frac{b - d_{pl}}{2},\ \text{mm};\quad f = \frac{V_s}{t_s},\quad \text{min}^{-1},$$

where b is the width of flight tip; d_{pl} is the diameter of plasma forming nozzle; V_s is the surfacing rate; t_s is the surfacing step (1.5–2.0 mm).

The proposed procedure allows orienting in the selection of the optimum parameters of surfacing mode, which in practice shall be specified depending on thermophysical properties of base and filler materials, fraction of powder and PTA torch design.

Equipment for surfacing. Plasma-Master Ltd. Company has developed two types of equipment for PTA surfacing of screws of extruders and automatic molding machines. These are installations developed based on turning lathes having own bed with rotator and rear center.

In the first case the lathe is used as a ready-made bed, on support of which specially developed surfacing apparatus RM-300 is installed. It contains PTA torch, oscillation mechanism with corrector, power feeder, lifting mechanism and control panel. The dimensions of lathe are selected depending on the maximum length of deposited parts. Kinematics of the lathe after small transformations allows rotating the part with necessary rate and moving the apparatus with PTA torch with set surfacing step. The process of surfacing is regulated from one panel located on the apparatus.

The control system is made on the basis of PLC, which allows accurately adjust to a pitch of screw flights and follow the process parameters. The installation also includes a control cabinet, inverter welding power source and autonomous cooling unit of the PTA torch. Such type of installation is reasonable for development if the Customer has available turning lathe of necessary length. Regardless, some inconveniencies in work, such an approach allows significantly reducing total cost of the installation. Figure 10 shows an example of such installation.

In other cases it is more reasonable to use special installation RM-307 (Figure 11). It initially contains all necessary mechanisms driven from general panel. Step motors are used as drivers. The guides, on which the surfacing apparatus is moved, are located on a beam in the top part of the installation that allows preventing falling on them of filler powder and, thus, their preliminary wear-out.

The installation uses a rotator with tilt axis, which permits surfacing of cylinder as well as conical edge surfaces. In becomes more versatile in such a variant. The installation can surface the cylinder parts of 20–300 mm diameter and 4500 mm length in automatic and semi-automatic modes. Number of steer axes can be from 3 to 5.

Consumables. Following the conditions of operation and design peculiarities of screws of extruders and automatic molding machines, the alloys designed for their surfacing shall satisfy a series of requirements. In addition to high wear-resistance, they shall have sufficient corrosion resistance at processing of aggressive polymers, good compatibility at friction with cylinder metal and high technological properties in surfacing. Nickel and cobalt based alloys are the most often used in the world practice for these purposes. In order to eliminate cracks in the deposited layer the parts are preheated till 400–500 °C temperature and sometimes concurrent heating is used.

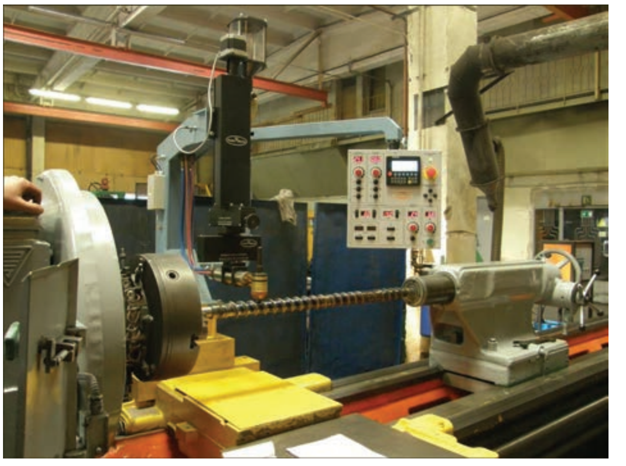

Figure 10. Installation for PTA surfacing based on turning lathe and apparatus RM-300

The experience shows that preheating of such parts not only complicates the surfacing process, but significantly raises its price. Wear- and crack-resistant alloy based on iron of Fe–Cr–V–Mo–C system [9, 10], was developed especially for PTAS of screws with the participation of author. Today, it is produced in form of powder of PR-Kh18FNM grade (PMalloy21). This alloy refers to high-vanadium cast iron class. The peculiarity of structure of this alloy is very fine grain (10–15 μm) and fan-shaped form of eutectics, located as separate colonies like being implemented in austenite-martensite matrix (Figure 12).

Such eutectic structure provides alloy with combination of high strength and ductility $\sigma = 1000$ MPa and $\alpha_s = 25 \cdot 10^2$ MPa. Metal hardness after surfacing makes *HRC* 43–45. After tempering at 650 °C temperature for 2 h its hardness due to secondary hard-

Figure 11. Installation RM-70 for PTA surfacing of screws of extruders and automatic molding machines

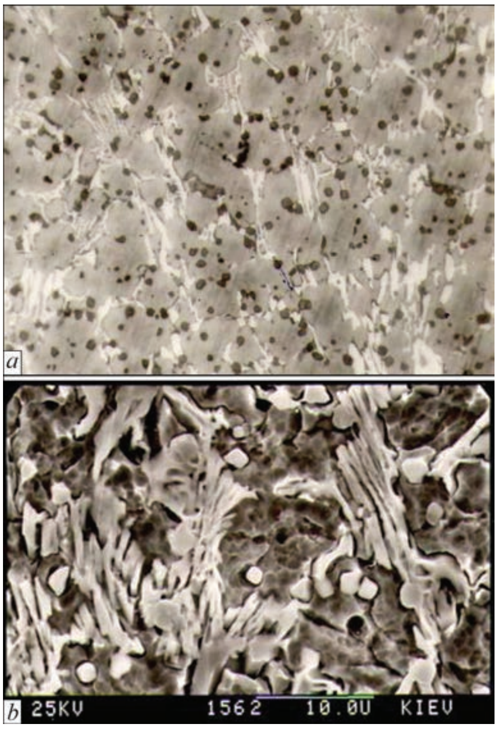

Figure 12. Microstructure of metal, deposited with powder PR-Kh18FNM (PMalloy21): *a* — optical microscope (×500); *b* — electron microscope (×3000)

ening rises to *HRC* 52–53. The main wear-resistant phase of the alloy is vanadium carbides VC.

Powder of PR-Kh18FNM grade (PMalloy21) is widely used in industry for surfacing of screws in Ukraine, Russia, Poland and other countries. A huge experience on surfacing and operation of deposited parts in processing of pure as well as filled polymers has been accumulated for more than 20 years period. The powder provides excellent formation of deposited metal (Figure 13) and absence of cracks even in small massive parts at correct choice of surfacing modes. This important technological advantage of given alloy allows rejecting from preheating of billet and, thus, significantly simplify surfacing process.

It should also be noted that surfacing allows not only repairing the expensive part, but considerably rising its wear resistance. In comparison with new nitrated screws the repaired parts demonstrate 3–5 times higher resistance depending on type of processed material. It is also 1.2–1.5 time higher when comparing with the screws deposited with PG-SR3 and Stellite 6 alloys.

Conclusions

1. Shape of bead at plasma surfacing on narrow tip of screw flight depends on fullness (cross-section area), deposition rate and PTA torch zenith displacement. To provide the best bead formation it is necessary that zenith displacement equals to approximately 2/3 of weld pool length, and length of the pool itself shall not exceed 0.22–0.26 of part diameter.

Figure 13. Fragment of deposited screw of 63 mm diameter

2. The proposed procedure for selection of screw surfacing modes allows orienting on the selection of the main process parameters, namely arc current, deposition rate, powder feed and PTA torch zenith displacement depending on part geometry, i.e. diameter, width and height of flights.

3. Developed equipment, technology and surfacing powder PR-Kh18FNM (PMalloy21) allow efficient repair of worn-out screws as well as significant rise of their wear resistance in comparison with new nitrated parts.

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