THE INNOVATIVE POST-WELD FINISHING METHOD AND NON-STANDARD CUTTING TOOL FOR CARRYING OUT THIS METHOD

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Abstract: The most common method of post-weld finishing is grinding with an abrasive tool. This finishing method leads to the occurrence of faults on the treated surface: locations missed or hardened twice, structural notches and stretching residual stress in the surface layer. The faults mentioned lead to the creation and development of ordinary as well as fatigue cracks, seizing or other damage. In addition, grinding is a process that often involves manual labour, which significantly increases the time required for finishing the procedure. Moreover, it is impossible to automate this process. Also, grinding is a process that is damaging for both people and the environment. In contrast to grinding and other processes of post-weld surface finishing, the innovative method, which is the subject of this article, does not have the faults and inconveniences of the previously mentioned techniques. The post-weld surface finishing method by moving of the innovative multi-edge cutting tool along the weld bead is presented in this article. In this method, machining allowance is treated as the weld bead height, which is flush-removed with the base material in one step during one pass of the cutting tool. The adjacent teeth height of changing and increasing according to the direction of feed and the difference in height between the first and last teeth are equal to the weld bead height. The number of cutting teeth necessary to flush-finish the weld bead with the base metal surface depends on the difference in the first and last teeth height and how it is divided. The tooth length is greater than half of the distance between the adjacent cutting teeth, which enables finishing the heterogeneous post-weld surface with many defects and increased hardness. The innovative method is characterised by short machining time of the weld bead and provides an accurate, efficient and economical process.

Key words: weld bead surface, physical model, broaching, multi-edge cutting tool

1. INTRODUCTION

In industrial enterprises, the most common method of post-weld finishing of surfaces is grinding with an abrasive tool of different shapes and using different abrasive materials. This finishing method leads to the occurrence of faults on the treated surface. The faults include locations missed or hardened twice, which creates structural notches in the surface layer, while also collecting residual stress (stretching) in these locations. The faults mentioned lead to the creation and development of ordinary as well as fatigue cracks and seizing and other damage. During the operation of welded constructions, the fatigue limit can be reduced, which can result in the destruction of the welded elements [1]. In addition, grinding is a process that often involves manual labour, which significantly increases the time required for finishing and impossibility of automating this process. Also, grinding is a process that is damaging for both people and the environment and necessitates the use of additional protective measures.

The innovative post-weld finishing method is a process of mechanical cutting, in which weld bead is removed flush with the base material in one pass of the tool. This process is characterised by the short machining time of the weld and high efficiency. In addition, this tool ensures a low level of deviations in terms of shape and position as well as exceptionally high machining accuracy and high quality of the surface layer with a surface roughness Ra = 0.32–2.5 [μm]. While helpful in eliminating unwanted welding defects on the bead surface due to the presence of cutting tool of the last two teeth of the same height and special geometry, the material removed in the form of chips accumulates in the chip flutes between adjacent blades. The shape and dimensions of the flutes depend on the shape, dimensions and properties of the weld bead material, the bead length and the feed per cutting edge. The feed value results from the design of the tool, with a gradual increase in the cutting teeth height, equivalent to the difference between adjacent edges (increment per one tooth). Wear of a properly designed tool is slow as its edges have a long service life thanks to the increased resistance to shock loads caused by increased tooth length. The work of the tool can be carried out on horizontal and vertical presses or machines of various types and designs. Depending on where the force is applied to the tool, it will be subjected to stretching or compression. The post-weld surface finishing method offers cost-effective machining, eliminating the need for skilled operators. Moreover, it demonstrates the capability to cut multiple weld beads arranged consecutively (continuous cutting) and enables the potential automation of the finishing process.

In the Polish patent document [2] can be seen a method and a device for grinding external longitudinal welds that involve grinding off the weld at a tangent to the surface of the external longitudinal weld and also along the weld with at least three passes of the grinder head preceded by rotation of the weld. The grinding equipment consists of a grinder head seated snugly in a support, a motor unit and a positioning device. The grinder head is fitted with a contact roller that is perpendicular to the line of the external longitudinal weld and comprises a tension roller, grinding tape, guide roller and pressure spring.

In patent document [3] can be seen a method and a milling machine for machining ridge welds of roller elements that have been joined together. The method involves movement of the ridge milling machine in a flat position, using chains, around the circumference of the connected cylindrical elements placed on a rotator, with the milling cutter's end mill removing the excess from the ridge of the weld previously placed on the joint of the elements that have been joined together. The milling machine consists of a housing, a hydraulic drive block for the cutter with a mechanism for regulating the depth of the milling, a hydraulic drive block for turning the wheels used for moving the milling machine to the lateral surface of the joined roller sections using chains, rollers leading the miller along the weld groove, a mechanism for correcting the movement of the cutter along the ridge of the weld and a mechanism for pulling the chains.

The application in the literature [4] discloses a method and device for machining a joint between two elements, in which a connecting material in the form of a weld is applied along the joint, then the joint of the connecting material is machined to a given cross-sectional shape by a profile cutting tool moved along the joint, and removing the outer layer from it, while at the same time clearing the machined outer layer by suction. What is advantageous is that a polyurethane-based sealant can be used as the connecting material. The tool that is appropriate for this purpose includes a suction nozzle with a suction opening and a cutting tool mounted on its edge; this tool can remove and guide the upper weld layer of the connecting material into the suction opening for removal to the outside.

In German patent document [5], it can be seen that the invention is related to a deforming and cutting broaching tool which has cutting and calibrating teeth and a deforming element fitted in front of the cutting teeth. The patent describes several design solutions of deforming and cutting tool for broaching holes and grooves. The main idea is the design of the deforming element with projections which result in a deforming and cutting broach, with the aid of which longitudinal grooves are formed on the surface to be machined, dividing this surface into sections which are limited in width. These sections are then machined from the incisors with continuous cutting edges. The width of the separated chip corresponds to the width of the respective section. As a result, the otherwise indispensable execution of chip separation grooves on the cutting teeth of the broach is eliminated. Owing to the omission of rapidly wearing angular sections of the cutting edges, the service life of the cutting teeth is significantly increased. In addition, the design of the cutting teeth with a continuous cutting edge contributes to reducing the workload in the manufacture and sharpening of the deforming and cutting broach. Since the height of the projections of the deforming element essentially determines the overall infeed of the cutting teeth, the compaction of the metal takes place in the depth of the grooves thereby formed, and the cutting teeth of the broach cut off sections of uncompact metal, which makes it possible to cut not only soft metals but also be able to process metals with greater hardness. Most advantageously, these forming and cutting broaches can be used for machining bores as well as for machining grooves and flat, stepped surfaces.

However, the design solutions of the forming and cutting broaches presented in this patent cannot be used for post-weld surface finishing, although they have similar elements. First of all, during post-weld surface finishing, it is not permissible to penetrate deep into the base material and form a groove on the weld surface. The weld bead can only be removed flush with the base material. Otherwise, the welded joint loses its reliability. Therefore, the tool for post-weld surface finishing must be designed in such a way that the difference in the first and last teeth height is equal to the weld bead height and the teeth width is equal to the maximum of the weld bead width. The total number of teeth necessary to finish flush the weld bead with the base metal surface must depend on the weld bead height (the difference in the first and last teeth height).

In addition, the tool teeth must have a specific geometry and an increased tooth length, so that the cutting process can occur without destruction of the cutting edge in interrupted cutting conditions with shock loads. The last teeth of the tool described in the patent are the calibration teeth. They serve to reduce the roughness of the machined surface. However, when processing a weld, the surface roughness is not of great importance. A much more important challenge is the elimination of fractures, craters, pores and other weld defects. In contrast to the solutions shown in this patent, the method which is the subject of this invention satisfies all the requirements described above.

In contrast to the grinding and other modern methods of post-weld surface finishing, the process of weld bead broaching, which is the subject of this article, does not have the faults and inconveniences found previously [6, 7].

2. RESEARCH MATERIALS AND METHODOLOGY

For processing various complex surfaces of different dimensions, shape and quality within one machining cycle (e.g. welded surfaces), it is necessary to use a non-standard cutting tool with a specialised design adapted to specific conditions: a multi-edged tool for post-weld surface finishing, thanks to the appropriate shape and cutting teeth location, correctly adjusted to the finishing conditions on the basis of strength calculations. This tool is used in the following conditions: intermittent cutting caused by the shape and properties of the weld bead surfaces, uneven machining allowance, variable number of simultaneously working (active) edges, discontinuity of the machining process, periodically changing or impact loads on the cutting, heterogeneity of the weld bead material and increase in tool wear.

These types of finishing conditions are characterised by variable loads on the cutting tool due to a cyclical cutting of the edges into the bead when the cutting force changes from Pmin = 0 to Pmax, causing non-cyclic loads.

The invention makes it possible to finish complex weld bead surfaces of various shapes and dimensions, various grades of steel and alloys, as well as automating the process, increasing efficiency and reducing the labour intensity of the machining process.

A tool which is a physical model of the broaching process was used for the research in the first phase [8–10]. Therefore, in order to carry out the research, a cutting tool of a special design was manufactured with changing cutting elements made of high-speed steel SW7M (HS6-5-2); then it underwent heat treatment (hardening at a temperature of 1,250°C and tempering at a temperature of 560°C to a hardness of HRC 62–65). The cutting element geometry was identical to the innovative cutting tool geometry which was used for weld bead broaching [10]. Four samples with the dimensions shown in Fig. 1. made of S235JR steel were prepared for testing.

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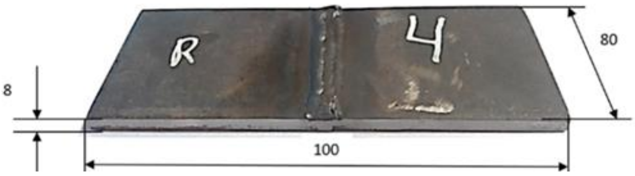

Fig. 1. Test sample displaying dimensions in millimetres

Samples were prepared for machining on the SZ-400 Planer, with welded samples using the different methods before and after planning, as shown in Fig. 2.

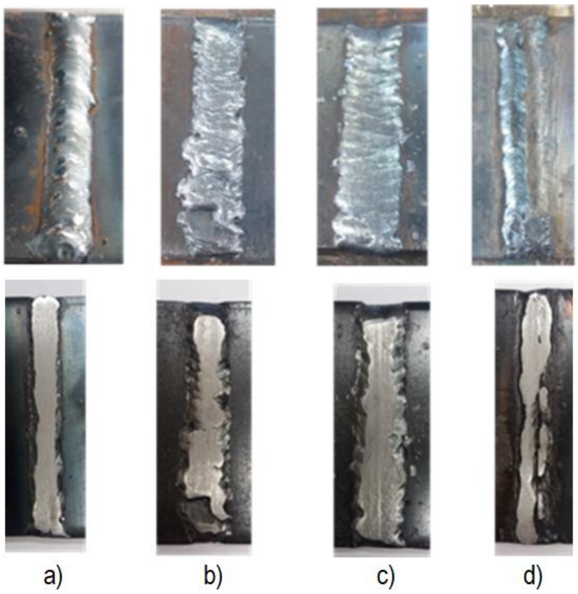

Fig. 2. Welded beads before and after planning: a) semi-automatic welding machine, welding amperage $I_{weld} \approx 95A$; b) semi-automatic welding machine, CO2, $I_{weld} \approx 110A$; c) semi-automatic welding machine, CO2; Corefil 100R Metalweco wire Ø 1.2 mm; $I_{weld} \approx 90 – 110A$; d) manual metal arc welding (MMA), $I_{weld} \approx 90A$

The experiment has shown a stable cutting process with good quality of the treated surface. Therefore, we started the second phase of the research related to the calculation and design of the non-standard multi-edge cutting tool, the fixture for its fastening and the choice of the machine for testing of the innovative method in an industrial environment.

3. CALCULATIONS AND DESIGN

In order to prepare the multi-edged tool for post-weld surface finishing intended for machining a specific batch of weld-joints, it is necessary to design it using existing calculation methods [11–17], but also applying new non-standard solutions.

In order to calculate and design the multi-edged tool, a set of welded joints were prepared using various welding methods (MMA, MIG, TIG). The test samples were made of S235JR steel and were prepared for testing as shown in Fig. 3.

First of all, the machining allowance q_p is determined. When finishing the weld bead flush with the base metal surface, the allowance q_p is treated as the weld bead height H_s (Fig. 4), which is limited by the surfaces of the finished object a_p and the weld bead a_s and is equal to the difference in the first and last cutting teeth height.

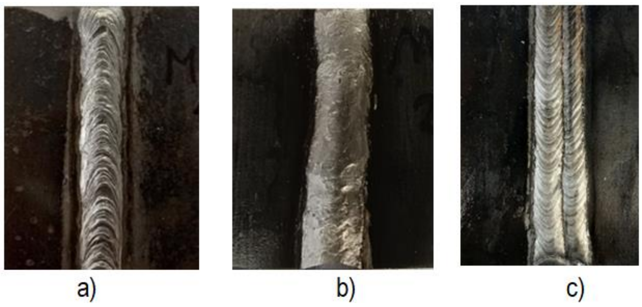

Fig. 3. Welded joints produced using various welding methods: a) MMA; b) MIG; c) TIG

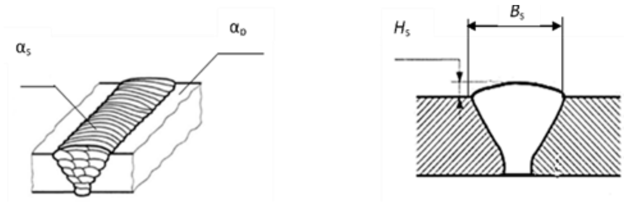

Fig. 4. Weld bead elements

In order to determine the machining allowance q_p it is necessary to measure the weld beads height H_s, then statistical analysis of measuring results is carried out. Before calculation and designing of the cutting tool, the maximum dimensions of the weld beads are determined for processed seams in the batch. On the basis of the analysis performed, the extreme weld bead height H_s and the weld bead width B_s are determined (Fig. 4). In the welded samples under consideration, the maximum weld bead height H_{smax} = 3 mm and the maximum weld bead width B_{smax} = 15 mm. Consequently, the machining allowance $q_p = H_{smax}$ = 3 mm. After determining the machining allowance q_p, the value of the feed per tooth a (thickness of cut layer) needs to be established. The division of the allowance at rectilinear edges is the division of the allowance thickness on the total width of the machining (Fig. 5).

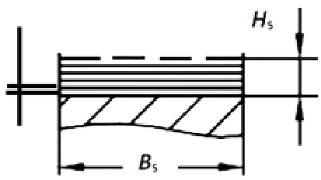

Fig. 5. Division of machining allowance at rectilinear cutting edges

In the example, the thickness of the layer being cut is a = 0.2 mm. Its value was selected with reference to the shape and geometry cutting teeth, the type of the material being processed and the technical capabilities of the machine tool (press).

The next step in the design of the tool is to determine the geometry of the cutting edge. For finishing flat surfaces, cutting teeth are made with an inclination of angle ω°, which reduces the concentration of the cutting force on the cutting edge. The angle of inclination of the cutting edges can be 0°, 10°, 15° or 20° [14].

The direction of chip flow depends on the inclination angle of the edge and should ensure free removal of chips from the surface of the workpiece without the interaction of the cut material (chips) with adjacent cutting teeth. After selecting the angle of inclination of the cutting edge, a checking process to determine whether the value of the lateral cutting force P_x, arising at ω ≠ 0 ° (Fig. 6), will not push the cutting tool away.

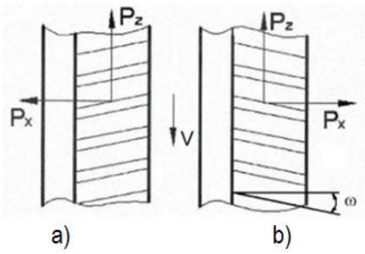

Fig. 6. The system of cutting forces in tools with the inclination of the cutting edges [14]

In the case shown in Fig. 6a, the direction of the side force P_x will press the cutting tool against the tool body and will not adversely affect the machining process. However, in the case shown in Fig. 6b, the direction of the side force P_x will cause repulsion, which may have a negative impact on the machining accuracy and will require the use of additional equipment (compensators). However, the use of inclined edges complicates the tool-making process and increases the time required and cost. For these reasons, ω = 0° was assumed [14].

To ensure reliable operation of the tool under shock loads, it was necessary to strengthen the teeth of the tool. The approximate value of the cutting teeth pitch P_p is determined using the formula:

$$P_p = (2.25 \ldots .3)\sqrt{L} \tag{1}$$

where L is the weld bead length in millimetres, ensuring trouble-free chip removal.

At the same time, tooth length dimension g was increased, strengthening the cutting edge, without changing the length of flute k, which is set using the following formula:

$$k = (1.05 \ldots 0.95)\sqrt{L} \tag{2}$$

The edge height *h* is determined in the range:

$$h = (0.55 \ldots\ 0.7)\sqrt{L} \tag{3}$$

The rake angle γ of the cutting edges is determined depending on the type and properties of the processed material. A rake angle of *γ* = 20 ° is used. The application angle α is determined depending on the machining stage [15]: stripping blades α = 3°; cutting edges α = 2…3°; finishing edges α = 1° and spare edges α = 0°30´. In the example, the application angle is α = 3°[14].

The remaining parameters of cutting tooth are determined using the formula:

$$g = P_p - k,\ \ r = (0.5 \ldots 0.6)h,\ R = (0.65 \ldots 0.8)P_p \tag{4}$$

where P_p is the pitch value of cutting teeth, g is the tooth length, k is the flute length, r is the radius of the bottom of the flute and h is the edge height.

After determining the geometry of the cutting teeth, the strength of the multi-edged tool for post-weld surface finishing is checked, depending on the cutting forces. Changes in cutting force values when machining welded surfaces can be caused by the difference in the height of the removed weld, a variable number of simultaneously working (active) teeth, a change in the properties (heterogeneity) of the processed post-weld material, and the formation and disappearance of build-ups in the chip formation process.

Depending on the value of the change in cutting force *F*, there are three varieties of tool load [11]: constant, periodically varying from F_{min} to F_{max} and pulsating.

The variation of the tool load can be determined by the following coefficients:

– *load constancy factor* u:

$$u = \frac{F_s}{F_a} \tag{5}$$

where F_s is the average value of the cutting force and F_a is the amplitude of the cutting force.

$$F_s = \frac{F_{max}+F_{min}}{2},\qquad F_a = \frac{F_{max}-F_{min}}{2} \tag{6}$$

– the load variation coefficient e is the inverse of the load constancy coefficient:

$$e = \frac{1}{u} = \frac{F_a}{F_s} \tag{7}$$

– load cycle asymmetry coefficient r:

$$r = \frac{F_{min}}{F_{max}} \tag{8}$$

– the dynamic load factor ζ is the inverse of the load cycle asymmetry factor:

$$\zeta = \frac{1}{r} = \frac{F_{max}}{F_{min}} \tag{9}$$

In the process of innovative weld finishing, we assume tool loads periodically varying from F_{min} to F_{max}. This variation depends on the number of simultaneously working (active) edges contained in the range from

$Z_{min} = 2$ to $Z_{max} = 8$, where $Z_{max} = Z_{min} + 1$.

The load variation coefficients will be [11,12]:

$$u = \frac{F_s}{F_a} = \frac{F_{max}+F_{min}}{F_{max}-F_{min}} = \frac{F_z Z_{max} + F_z Z_{min}}{F_z Z_{max} - F_z Z_{min}} =$$

$$= \frac{F_z(Z_{min}+1)+F_z Z_{min}}{F_z(Z_{min}+1)-F_z Z_{min}} = 2Z_{min} + 1;$$

$$e = \frac{1}{u} = \frac{F_a}{F_s} = \frac{1}{2Z_{min}+1};$$

$$r = \frac{F_{min}}{F_{max}} = \frac{Z_{min}}{Z_{min}+1};$$

$$\zeta = \frac{1}{r} = \frac{F_{max}}{F_{min}} = \frac{Z_{min}+1}{Z_{min}} \tag{10}$$

The numerical values of the coefficients are shown in Tab. 1.

Tab. 1 Numerical values of coefficients of variation of tool loading

Number of simultaneously operating edge	Load variation coefficients			
	u	e	r	ζ
from 1 ….2	5	0,200	0,667	1,500
3	7	0,143	0,750	1,333

4	9	0,111	0,800	1,250
5	11	0,090	0,833	1,200
6	13	0,077	0,857	1,167
7	15	0,067	0,875	1,143
8 to 10	17	0,059	0,889	1,125

From the analysis of the above numerical dependence of the coefficient values, the obvious conclusion is that as the number of simultaneously working (active) edges increases, the load variation decreases.

As shown above, the cutting force when machining post-weld surfaces varies from F_{min} to F_{max}. On the other hand, the cutting force can take over not only positive values, but also be zero $F_{min} \geq 0$. At the moment when the active blades of the cutting tool lose contact with the machined surface, the value of the cutting force of the smallest $F_{min} = 0$. The actual change in forces takes place only in the positive range, and the stresses on the tool material caused by the action of such a cutting force will carry the same character.

$$F \in [0 - F_{max}], \sigma \in [0 - \sigma_{max}] \tag{11}$$

Unilateral alternating stresses σ_j can be compared with the fatigue strength Z_j of the tool material. Then the allowable es k_j are determined relative to the fatigue strength after assuming a certain value of the safety factor x_z:

$$\sigma_j = \frac{F_{max}}{A} \leq k_j, \quad k_j = \frac{Z_j}{x_z} = \frac{0{,}6 \cdot 2100}{4{,}85} = 260\ MPa \tag{12}$$

The value of the fatigue strength for unilateral stresses of high-speed steel (approximately) is expressed in relation to the static strength R_m with the relation $Z_j = (0.5 \ldots 0.75)R_m$.

For the design of the tool, we adopted the material high-speed steel SW7M (HS6-5-2) subjected to heat treatment (quenching at 1,250°C and tempering at 560°C to hardness HRC 62–65). For this material, we assume an intermediate value $Z_j = 0{,}6R_m$ and an ultimate strength 2,100 MPa.

We determine the safety factor $x_z$from the formula:

$$x_z = \beta\gamma\delta = 1.72 \cdot 1.39 \cdot 2.03 = 4.85 \tag{13}$$

where β is the stress concentration factor ($\beta = 1.72$), it depends on the condition of the surface layer; γ is the tool size factor ($\gamma =$ tor ($\gamma = 1.39$)and δ is the actual safety factor ($\delta = 2.03$).

The actual safety factor can be expressed by the product of four partial coefficients:

$$\delta = \delta_I\delta_{II}\delta_{III}\delta_{IV} = 1.35 \cdot 1.05 \cdot 1.3 \cdot 1.1 = 2.03 \tag{14}$$

where δ_I is the material strength spread factor ($\delta_I = 1.35$); δ_{II} is the material control quality factor ($\delta_{II} = 1.05; 1.1; 1.15$); δ_{III} is the tool validity factor ($\delta_{III} = 1.3$); δ_{IV} is the machining quality factor (rough machined ($\delta_{IV} = 1.04 \ldots 1.07$) or raw ($\delta_{IV} = 1.07 \ldots 1.1$)). All values of the coefficients are selected for the conditions of approximation for broaching (pushing) of post-weld surfaces with the SW18 high-speed steel tool based on the data in the publication [12].

When designing a pushover, it is necessary to check the conditions of compressive strength and buckling.

The compressive stress that occurs in the pusher material should be less than its permissible value:

$$\sigma_c = \frac{F}{A} \leq k_c \tag{15}$$

where σ_c is the compressive stress; F is the compressive force of the pusher ; A is the area of the dangerous smallest section and k_c is the permissible compressive stress.

When the compressed tool has a high slenderness the danger of buckling arises. The slenderness of the pusher is determined from the formula:

$$\lambda = L\sqrt{\frac{A}{J_A}} \tag{16}$$

where L is the length of the pusher and J_A is the moment of inertia in mm^4 of the dangerous cross-sectional area $A = BH$ mm^2.

Taking into account that the moment of inertia of a rectangular section is:

$$J_A = \frac{BH^3}{12} \tag{17}$$

is determined:

$$\lambda^2 = 12L^2\frac{BH}{BH^3} = \frac{12L^2}{H^2} \tag{18}$$

Elastic buckling of the pusher occurs when the critical value of compressive stress is reached, calculated from Euler's formula:

$$R_{kr} = \frac{k_0 E}{\lambda^2} \tag{19}$$

where k_0 is a coefficient that depends on how the ends of the pusher are fixed ($k_0 = 9.87$), E is the the longitudinal modulus of elasticity for high-speed steel $E = 2.2 \cdot 10^5$ MPa.

After calculating the permissible compressive stresses and buckling of the pusher, the lower value from these calculations is taken for further design.

The final design stage involves the creation of a dimension table for the teeth of the multi-edged tool, determining its total length and preparing a shop drawing for the tool. Before creating the table, it is necessary to determine the nominal values of the total height of the cross-section for each tooth.

The final design stage involves the creation of a dimension table for the teeth of the multi-edged tool, determining its total length and preparing a shop drawing for the tool. Before creating the table, it is necessary to determine the nominal values of the total height of the cross-section for each tooth.

The value of the section height of each successive teeth increases by the value of the feed per one tooth a (thickness of the cut layer). So the height of the H_i – tooth is given by the formula:

$$H_i = H_1 + (i - 1) \tag{20}$$

The table is filled in until the shop drawing is started and it contains the numbers of all the teeth in turn, their height with deviations and the value of the application angle $\alpha°$ as appropriate for each group of the teeth (Tab. 2).

The total number of teeth $Z_o$necessary to finish flush the weld bead with the base metal surface is dependent on the weld bead height (the difference in the first and last teeth height – machining allowance q_p:

$$Z_o = \frac{q_p}{a} + 1 \tag{21}$$

where a is the thickness of the cut layer in millimetres.

Tab. 2. Parameters of cutting teeth

Angle of application	α = 3°																
Deviation	- 0.02																
Tooth number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tooth height H_i, mm	30.0	30.2	30.4	30.6	30.8	31.0	31.2	31.4	31.6	31.8	32.0	32.2	32.4	32.6	32.8	33.0	33.0

The one in the above dependence results from the fact that the first tooth is made of the same dimensions as the leading part, so it does not participate in the cutting process. The total number of teeth was increased by adding the penultimate and last teeth, which have the same height to eliminate crack, craters, pores and other weld defects.

The cutting tool is then manufactured in a traditional manner in accordance with the calculated parameters and specific cutting tooth geometry [10–12]. It is mounted in the machine tool or press holder, and moved along the weld bead. The weld bead can only be removed flush with the base material. Otherwise, the welded joint loses its reliability.

4. TECHNOLOGY DEVELOPMENT

The thesis of the process of creating an innovative method is effective removal of the weld root (face) in open areas with different types of welded joints with a guarantee of maintaining shape accuracy and high requirements to the quality of the surface layer while ensuring the safety of work and the non-obtrusiveness of the process to man and the environment. According to the stated thesis, several important assumptions were formulated, which were taken into account during the development of innovative weld finishing technology:

– the machining process of the cutting tool that is the subject of the present invention is a machining process of chip machining, in which the entire machining allowance must be cut within one pass of the tool;
– such a process is to provide a short weld machining cycle time and high productivity;
– the tool is to provide low deviations in shape and position and high machining accuracy and surface layer quality with a surface roughness of no more than Ra = 0.32–2.5 [μm];
– the invention must make it possible to machine complex weld surfaces of different dimensions, from different steels and alloys;
– the method is to increase productivity and reduce the labour intensity of the machining process.

The Hydraulic Broaching machines BM25 NARGESA was chosen for the implementation of this technology. The machine BM25, has been thought for small medium productions and is characterised by its great versatility, reliability, easy use, fast setting up, effectiveness and incorporates all safety devices according to CE regulations. The majority characteristics of the machine are motor power – 2,2 Kw; 3-phased tension – 230/400 V; hydraulic power – 10 t; max. broaching capacity – 25 mm; working speed – 24 mm/s; return speed – 54 mm/s and bench dimensions – 420 mm x 420 mm.

The specialised device shown in Fig. 7 was designed and manufactured for homing and fixing the sample (welded joint) and the cutting tool.

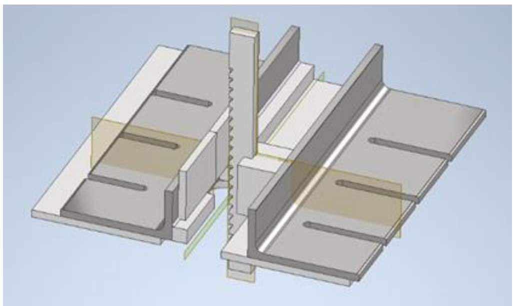

Fig. 7. The device for realising the innovative post-weld finishing method [18]

As a result of the design and calculations, the weld beads finishing technology was developed in accordance with the innovative method (Fig. 8).

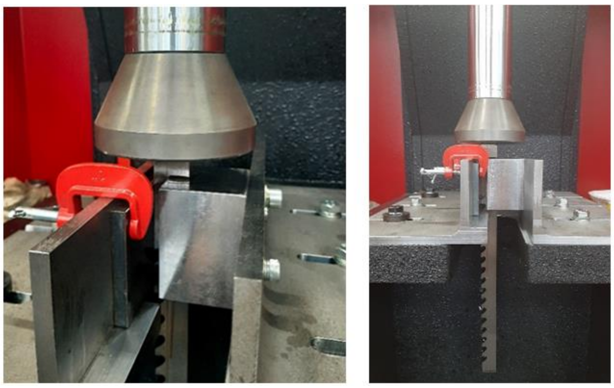

Fig. 8. Finishing of the butt weld joint using the innovative method and tool [18, 19]

In order to verify (test) the developed technology, samples of butt welded joints were made of different materials: unalloyed structural steel, stainless steel and aluminium alloy were subjected to mechanical treatment. The samples after removing the weld face according to the innovative method are shown in Fig. 9.

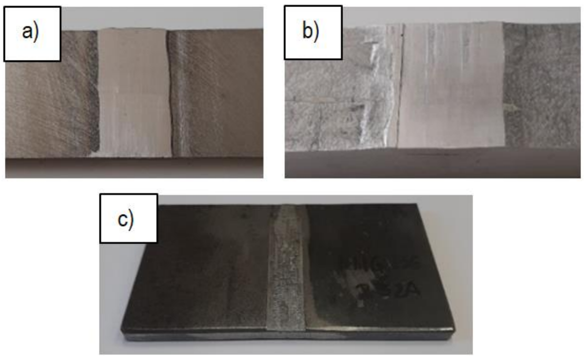

Fig. 9. Weld bead after the finishing [18, 19]: a) stainless steel 1.3964; b) aluminium alloy PA47(7020); c) unalloyed steel S235JR

After conducting extensive testing of the innovative method, numerous benefits and advantages have been unveiled:

- short processing time;
- high productivity and high accuracy;
- low deviations in shape and position;
- high quality of the surface layer;
- the possibility of automating the process;
- reduction of production costs;
- low environmental nuisance;
- applicability of the weld processing solution in a wide range of products from different steels and alloys;
- does not require complex machinery;
- short implementation process;
- the possibility of machining welds of different shapes and dimensions, made by many welding methods.

The proposed method of post-weld surface finishing will find wide application in the production processes of welded structure elements and subassemblies and machine parts made using welded methods. The data of the world-wide solution can be successively used in various industries, that is: marine engineering, aerospace, armament, railroad and other mechanical engineering industries.

5. CONCLUSIONS

The innovative method is characterised by the short machining time of the weld bead and high efficiency. In addition, the innovative multi-edge cutting tool is used for weld bead finishing and ensures a low level of deviations in terms of shape and position as well as exceptionally high machining accuracy and high quality of the surface layer. While helpful in eliminating welding defects on the bead surface due to the presence on cutting tool of the last two teeth of the same height and special geometry of cutting teeth, wear of a properly designed tool is slow as its edges have a long service life thanks to increased resistance to shock loads caused by specialised tooth geometry based on strength calculations. The innovative weld bead finishing method provides economical machining, not requiring qualified operators, as well as the ability to cut many weld beads set in a row (continuous cutting), and the possibility of automating the finishing process. The versatility of the solution allows for the post-weld surface broaching of various types of steel and alloys using the overwhelming majority of welding methods. This solution exhibits no detrimental effects on individuals or the surrounding environment, while also complying with all emission standards and regulations. This invention provides accurate, efficient and economical post-weld finishing.

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