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ANALYSIS OF IN-SITU RENEWAL TECHNOLOGY FOR THE BACKHOE BUCKET BORES

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Abstract

The overall aim of this article is to outline the progress of the research on how to develop an economically and scientifically justified backhoe buckets boreholes renewal technology by using mobile on-site technological equipment. Today the new mobile (in-situ) repair technologies are extensively used for the specialized equipment and machinery repairs. This repair technology is deployed directly on the damaged product: repair equipment is installed by using specialized centering devices. The bucket bores central axes are used as a reference base and damaged layer of material is removed mechanically applying turning operation. Subsequently the renewable surface is covered by new material layer by means of regular MIG/MAG welding. The last technological operation is final turning to the nominal diameter. Outlined renewal technology should meet high expectations – this necessitates in-depth and systematic study of pins and bores which are the most repaired objects of shovel bucket excavators. Therefore, research on established accuracy and technical requirements, both for the repaired unit and technological equipment in line with in-situ repair technology specifics, has been done. It was supported by impact analysis of the technological regimes to surface integrity with ambition to provide practical recommendations for the optimal choice of the technological regimes.

Key words: *in-situ repair technology, surface integrity, technological parameters*

1. INTRODUCTION

Today in-situ repair technologies, supported by wide range of advanced equipment are providing excellent opportunities to considerably reduce overall repair costs. This in turn is prolonging significantly total life cycle of many industrial machines. Certainly these innovative technologies are requiring solid initial investment, yet in normal circumstances are rapidly paying back. In engineering practice it means that in-situ renovation machines are literary giving the second life to heavy loaded industrial units, such as buckets frames and hydraulic manipulators. The excellent advantage of these mobile technologies is the capability to repair the major large size units without dismantling them completely from the machine. Furthermore, these damaged parts can usually be repaired on excavation field and their transport to the workshop is not any longer required. This considerably shortens overall repair time and allows for much faster recovery of the excavation machine. Finally for all involved parties aforesaid know-how is providing considerable economy of financial resources and manpower.

Nevertheless, this mobile repair technology is having its limitations and difficulties too. These are mostly inherited difficulties related to surface integrity and surface quality, naturally arising from initial basing of the equipment and applied technological regimes. Hence this study is needed to further develop the renovation technology of the digging shovels and is devoted to the backhoe bucket bores which today are the most repaired working surfaces of excavation machines (see fig.1 – axis 1 and 2).

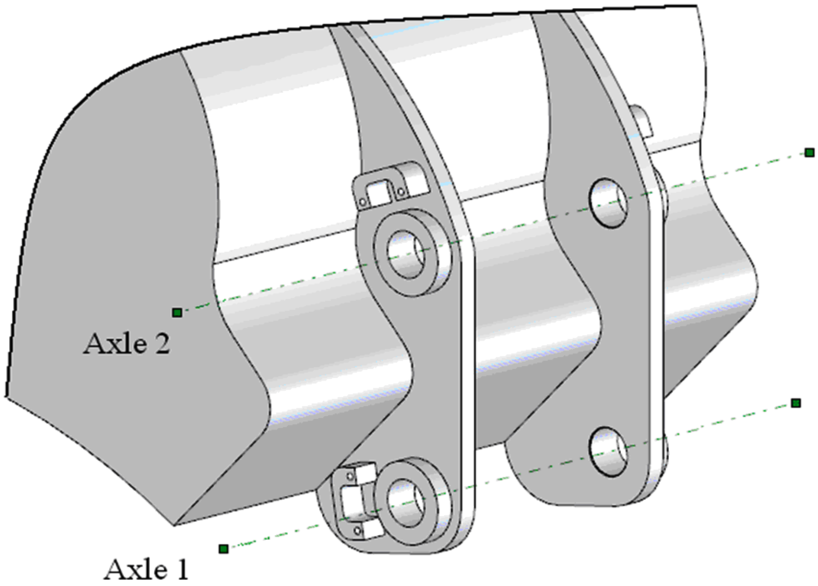

Figure 1 – Backhoe bucket bores

This article is covering the analysis of the renovation technology, bearing in mind the most important factors which are influencing the machining process. In the same time established technical requirements should be observed and respected when using this innovative repair technology. Naturally, the above mentioned renovation technique should meet all established precision and the high durability requirements. The output quality of repairs must ensure adequate operating performance and duration: in fact as for the new bucket. Surface roughness parameters and geometrical tolerances should respect the manufacturer's requirements or even exceed some of them. All this requires in-depth, systematic study of the buckets bores which on top of previously mentioned tough requirements are also the most heavily loaded parts of the buckets. In order to obtain comprehensive picture scope of this study should be extended to the common technical requirements, including: size tolerances, surface properties, surface roughness and cross-tolerances.

It goes without saying that accuracy of the reconstruction process has a direct impact on the final product. For the purpose of solving the main problems in the renovation process, the following issues should be addressed:

- In-depth technical requirements analysis;
- Detailed description and analysis of the production process;
- Accuracy requirements for the elaborated technological equipment;
- Analysis of the technological operations impact to the repaired unit surface integrity and quality;

- 3D surface roughness parameters should be considered.
-

2. ANALYSIS OF TECHNICAL REQUIREMENTS

Taking into account the large size of the bucket, the precision requirements set by manufacturers and applicable standards are quite challenging and difficult to respect in field repairs: parallelism tolerance 0.02, perpendicularity 0.5 and axial precision of 0.02 mm. Precision between main axes is 420±0.05 mm (see Fig.1 and 2). General tolerances are prescribed according ISO 2768 – m, and particularly for bucket bores with Ø$80^{+0.076}_{+0.030}$, surface roughness shall be Rz = 25 μm and surface hardness HB160.

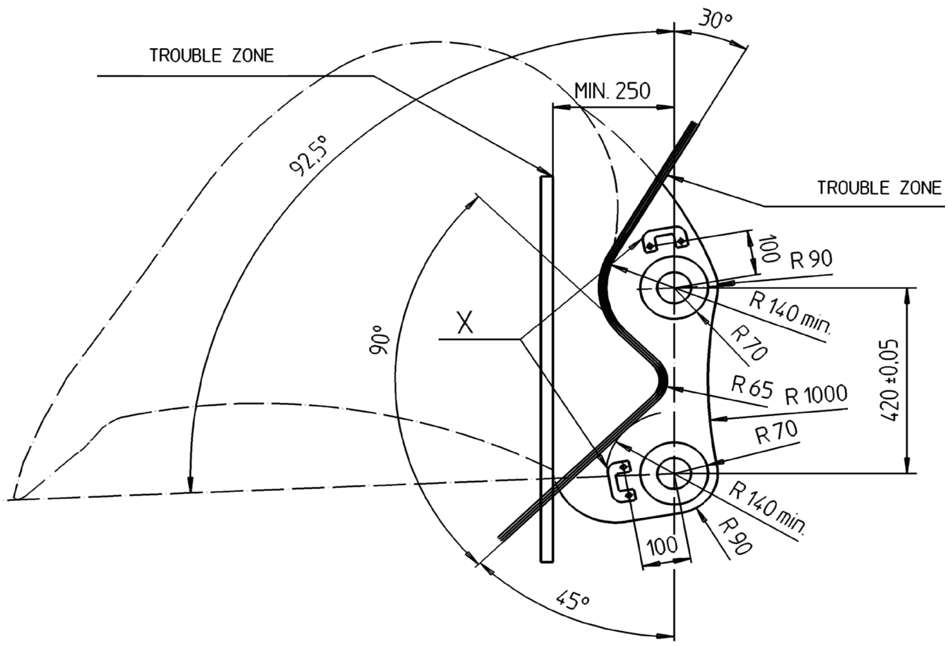

Figure 2 – Fitting dimensions – bucket

3. DESCRIPTION OF THE RENEWAL TECHNOLOGY

As it is mentioned above this mobile repair technology is realized by specialized equipment which is fixed directly on the damaged backhoe bucket. Sophisticated cantering devices are designed, and the bore central axes are used as a base (see fig.1.). The damaged layer of material is removed mechanically by internal turning operation. When it is done, the renewable surface is covered with the new material layer by conventional semi-automatic MIG/MAG welding. It is followed by final renovation operation: finish turning into the nominal bore size. Portable boring machine "Supercombinata SC1 40/1" (Italy) was used for this particular research [1].

Each element of this technology has a significant impact on the final result - surface integrity, especially the last turning operation. For that reason it is crucial to ensure that each manipulation delivers required quality. This should be adequately assessed and measured.

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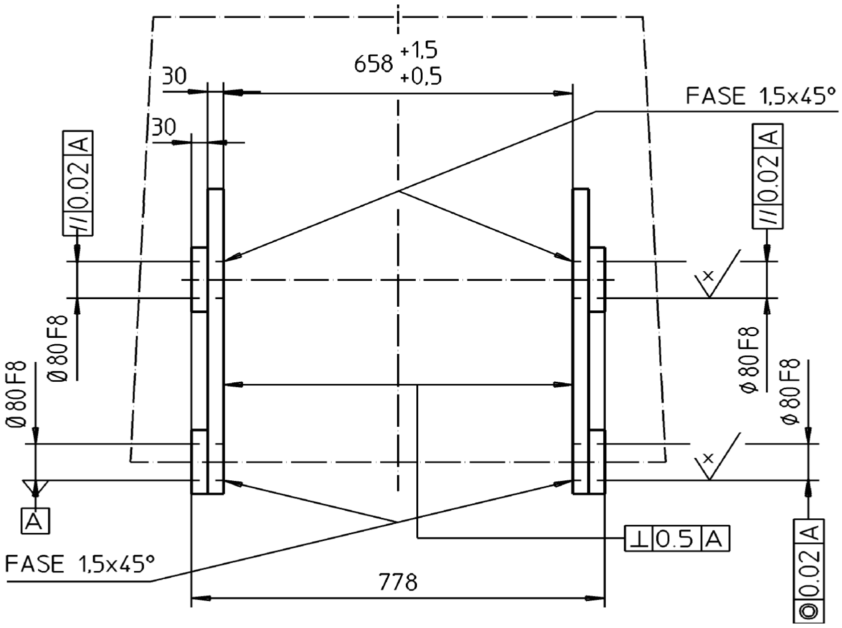

Figure 3 – Fitting Tolerances – bucket

3.1. Installation of the technological equipment

This is the first and the most consequential of all the technological operations. This operation is so important because the entire repair equipment is installed, fixed and adjusted only once and serves as a reference basis for all the following technological operations. Hence initial accuracy has paramount importance and it is imperative that it is double checked [2].

All installations and adjustments should be done in a way to reduce or remove any of resulting deflections, so there is no residual influence on the final accuracy. The allowed mounting error (installation tolerance) could be efficiently determined by analyzing requested or final tolerances. An installation error in this case is composed by singular equipment elements: base deviation errors towards backhoe boreholes surfaces and axes. Thus summary installation error can be computed by using common measurement circuit calculations; this is covered within subsequent sections of this article.

Principal elements required for repairs of digging pan are shown on fig.4. As said this equipment is installed directly on the damaged backhoe bucket. This includes the main shaft, restraints and set of centering cones, adjustment bolts and clamps, installation supports, etc. These accessories are complemented with adequate measuring equipment, including micrometers and laser leveling devices.

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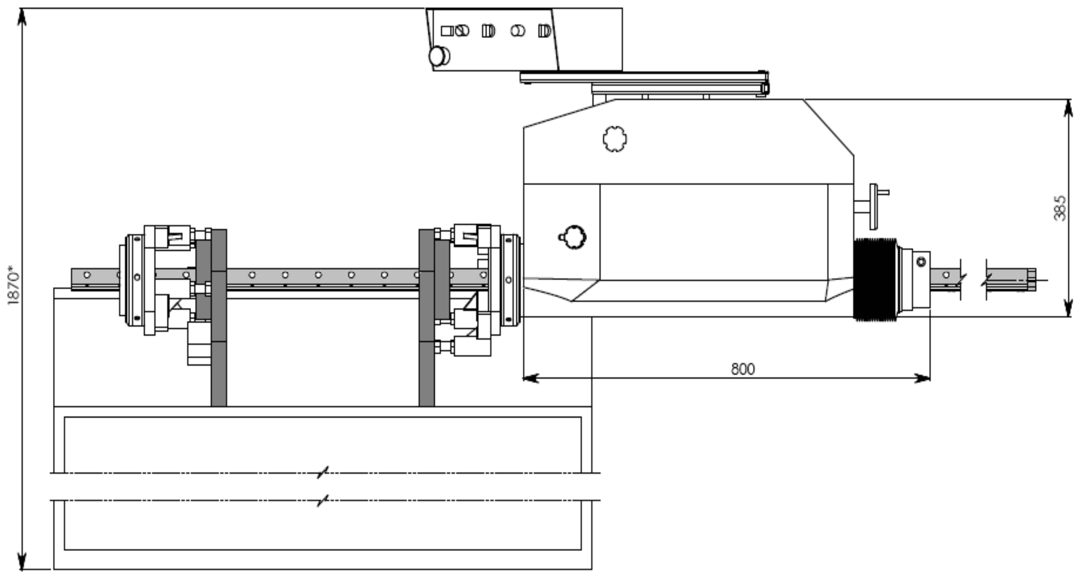

Figure 4 – Equipment installation scheme

Still in practice, it is extremely difficult to establish exact positioning of boreholes in relation to base plane and to peripheral surfaces, without using highly sophisticated measuring equipment. On top of that, surfaces which have to be repaired are usually severely damaged and cannot be used as a reference. For this reason in most cases technological equipment is fixed on the backhoe by using the peripheral surfaces as a main base (*B* – in fig.5). By peripheral surfaces we understand the surfaces which are firmly linked with renewable boreholes.

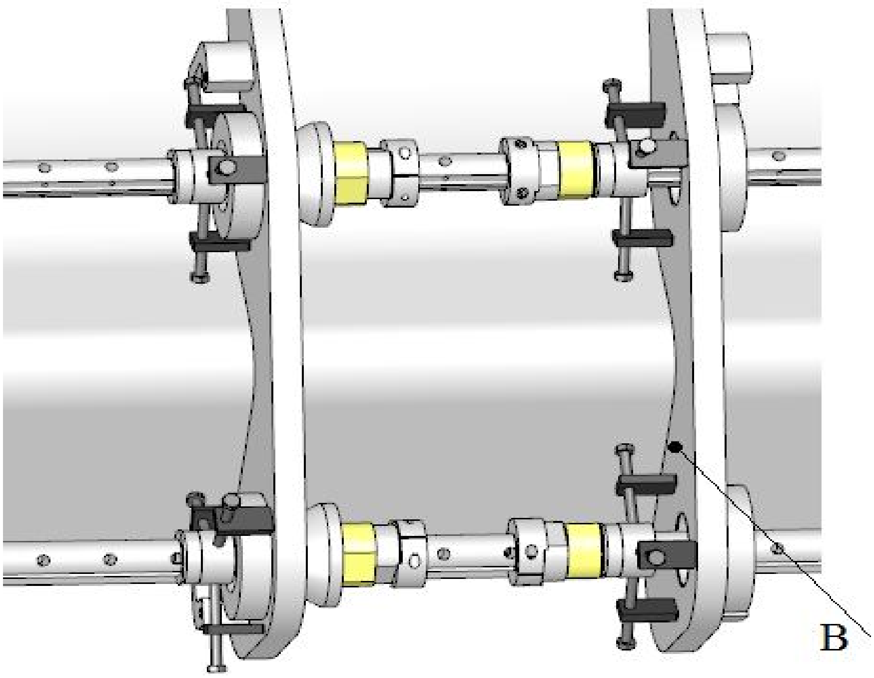

Figure 5 – Installation of the equipment

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Initial installation of equipment serves not only as a principal basis of all subsequent manipulations for the particular set of bores on one axel. This reference will be the same for all boreholes of bucket, even in cases where damaged axes are not in parallel. Thus principally new reference datum for boreholes is established and set-up (base error) is eventually eliminated.

It is important to bear in mind that during installation and all consecutive technological operations special care should be given to the accuracy of equipment and stiffness as well as to its overall performance. The following problematic aspects of installation could be encountered during repair operations:

- Substantially damaged reference base;
- General set-up/installation error;
- Incorrect assembly of technological equipment and its components.

Each of these deviations, if neglected, can negatively influence the outcome of repairs and for this very reason shall be considered and scrupulously checked.

3.2. Turning of damaged borehole

In this phase of renewal technology, the damaged surface is machined by turning, in order to eliminate the damaged (often irregular and/or elliptical-shaped) layer of material. The goal of this operation is to obtain a regular cylindrical surface which later will be filled with qualitative build-up welding. Although it does not seem obvious, this operation is no less important than others and should be performed in good quality. Only then machined surface could be efficiently covered with MIG/MAG welding. Hence the constant length of electro welding arc has to be delivered. Otherwise welding might be of very low quality and borehole surface can be uneven and layer of the new borehole material would not be homogenous. This operation is considered to be a preparatory one, but still has a major importance. Complementary turning equipment is shown in figure 6 and consists of a main shaft 1, cutting tool 2 and the cutting tool positioning-fixating screws 3.

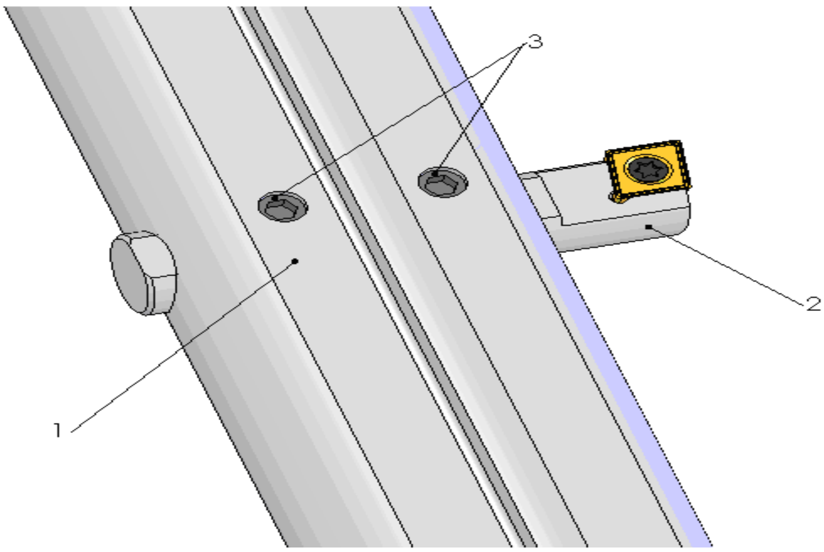

Figure 6 – Cutting tool fixation

Internal turning of damaged borehole should deliver smooth and precise surface, yet with maximized surface roughness. Rough surface formation is needed in subsequent build-up welding, to ensure better welding fusion with primary bucket material.

Research revealed some problematic aspects of the above mentioned rough turning operation: it has to face irregular allowance for machining, interrupted contact with surface and uneven strain hardening, which are typical characteristics of the worn-out backhoe bucket borehole. These factors have significant influence to the turning operation, resulting in uneven and irregular cutting pattern. It means that all technological equipment and in particular the cutting tool as well as the main shaft have to withstand great cyclic work loads and irregular impact load in the same time [3].

Therefore it is very important to determine the actual load effects on renovation equipment; especially on its critical parts. This must be accompanied by rigidity and stiffness cross-checks. All this is strictly related with defective product analyzes: the size and magnitude of the wear and tear, its nature and mechanical properties. These problems at certain extent are addressed within this paper, yet more attention is given to the successive technological operations.

3.3. Built-up welding

Also could be seen as a coating and should correspond to the material of backhoe buckets, which usually are made of steel S355J2G3. Accordingly the welding materials (wire and gas mixture) have to be carefully chosen and appropriate welding settings and regimes should be applied [4]. Technologically the build-up welding is done in several subsequent passages, building-up the necessary topping layers. Thus a new material layer is being formed and then machined by finishing turning. This final turning is delivering the end product: required geometrical parameters and tolerances are obtained. Still built-up layer should meet or even exceed the same mechanical characteristics as a new product (steel S355J2G3). Obviously welded layer of material should be able to withstand all existing dynamic loads of exploitation and even some additional safety strength reserve is required. Hence the eventual maximal load influence on backhoe bucket bores should be calculated. Although this issue is not covered by this article, it has been confirmed analytically and experimentally that chosen technology is able to fulfill the above mentioned criteria.

Build-up welding equipment of portable boring machine "Supercombinata SC1 40/1" consists of semi-automatic MIG/MAG welding apparatuses and standard set of equipment which is shown in Figure 7. Where 3 – gas supply tube fitted with welding wire. It is maintained in position 2 by check nut. Connected shaft is fixed to the main shaft of the machine by two bolts – 1. Welding nozzle - 5 can be regulated and adjusted into desirable position according to technological needs.

Coating process is depending on several factors which are directly affecting the overall quality of the renovated bucket bores. This is a reason why the most influential and thereby the most important ones should be considered for the further evaluation. To find out correlations between expedient technological regimes and obtained welding quality, series of experiments have to be conducted. Appropriate data collection methodology and evaluation criteria have to be established. Necessary measuring equipment and IT applications should be considered too. In order to proceed with this one should investigate the chemical composition, hardness, and mechanical properties of built-up welded material layer are. These components are essential to the further research.

Welding speed could be mentioned as one of the most important factors which are associated with the creation of smooth layer of build-up material. Still the optimal values of welding speed (V_{weld} m/min) can be established only empirically. Further very important factors are wire material itself and protective welding gas. The best welding torch positioning angle could be found again experimentally and require certain practical experience. On top of that, welding wire, gases, current strength and actual feeding have to be compatible with backhoe bucket material too and are subject for assessment.

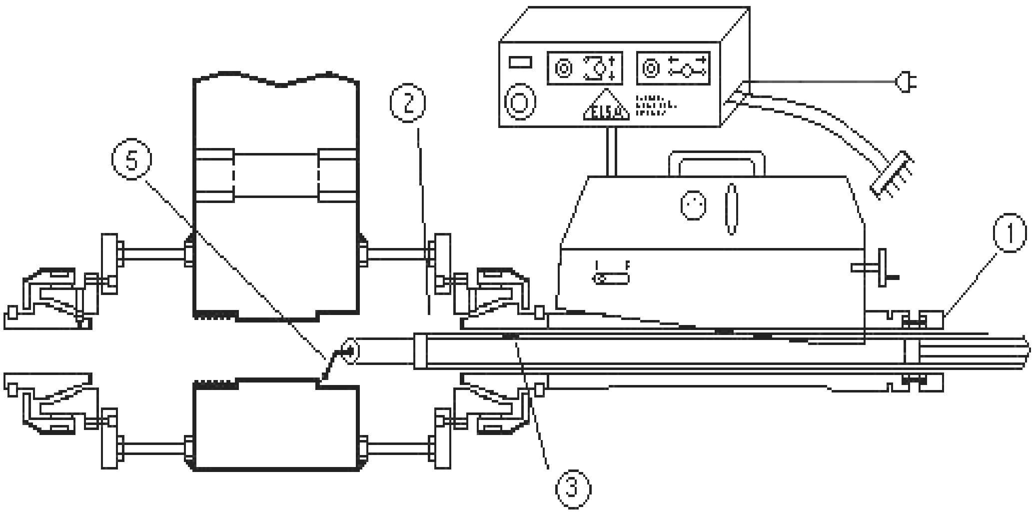

Figure 7 – Installation of welding equipment

Industrial practice confirms that coating for wear protection present the larger of applications for build-up welding. Here, alloys containing hard phases and pseudo-alloys with added carbides are used. Appropriate alloy composition could provide corrosion and high temperature resistance for built-up surfaces [5]. Four main groups of welding materials can be distinguished: nickel hard alloys, iron hard alloys, cobalt hard alloys (stellites) and aluminum pseudo-alloys. For this case it appears that wire EN440 G 4M 50 G2Mo with diameter of 1 mm is the most appropriate coating material for steel S355J2G3. Comparison of respective chemical compositions is summarized in Table 1.

Chemical elements	Wire EN440 G50 4M, %	Steel S355J2G3 max %
C	≤0.12	0.18
Si	0.4 - 0.9	0.15
Mn	1 - 1.5	1.6
P	≤ 0.025	0.03
S	≤ 0.025	0.015
Ni	≤ 0.2	
Cr	0.2 - 0.6	
Mo	0.2 - 0.6	
Cu	≤ 0.52	
Al		0.015 /min/
Nb		0.09
V		0.1
Ti		0.22

Table 1 –Chemical composition of welding wire and bucket material

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Protective gas optimally should have the following composition: RU 439 with M21 = 20% CO_2. When the chemical composition of gases and type of welding wire are known, one could proceed with the evaluation of the most appropriate mechanical regimes, gas supply, strength of electrical current, wire feed speed and welding speed. For this particular technology the most appropriate welding regimes, proved by practice, are given in Table 2.

Gas supply l/min	Electrical current A	Voltage V	Wire feed speed f_{wire} m/min	Welding speed V_{weld} m/min
15-20	250	30	8	0.7

Table 2 – Built-up welding technological Characteristics

Apart from the chemical composition the build-up material should possess similar physical and mechanical properties to a base material S355J2G3. These important properties are provided in Table 3.

Tensile strength N/mm^2	Min Yield Strength N/mm^2	Impact resistance at -20C^0 J	Hardness HB
500-620	355	27	160

Table 3 – physical properties of S355J2G3

Values obtained in the Table 1, 2 and 3 should be empirically evaluated and further experiments should be conducted. There are no credible tools to evaluate correlations between welding processes and build-up welding layer properties. For that reason empirical trials should be conducted with different materials in order to obtain sufficient knowledge and to be able to provide sound technological recommendations to the end user.

3.4. Turning to the nominal bore size

Is final technological operation and it should ensure required accuracy and surface roughness. Final turning will be carried out removing step-by-step the necessary amount of the coated material layer. Final result shall be controlled with the appropriate measurement technique. However, before final turning is commenced it is important to know what the mechanical properties are and the workability of the welded layer. It is important to remember that not only the geometrical tolerances and surface roughness parameters but also mechanical properties should respect manufacturer's recommendations. Furthermore technological regimes of this final operation should be chosen very carefully and should be supported by appropriate methodology which would easily allow linking these regimes with the delivered qualitative results. Table 4 contains the manufacturers' technological regimes for turning operations.

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Main shaft rotation frequency N, rev/min	Feed f, mm/rev	Cutting speed V, m/min	Cutting depth t, mm
1st stage: 40 – 120 2nd stage: 120 – 400	0.002-0.15	20-60	0.001- (5)

Table 4 – technological characteristics of turning operation

These technological regimes are indicative only. The rotation speed of the main shaft can be electronically regulated within broad interval of 0 – 2800 rev/min and other technological regimes can be adjusted accordingly. All of the above mentioned elements: MIG/MAG welding, rough and fine turning are subject to deeper evaluation and are covered hereafter.

4. ACCURACY REQUIREMENTS FOR DEPLOYED TECHNOLOGICAL EQUIPMENT

As a general rule the technological equipment must be at least one precision class superior to product which will be machined. In this case the workpiece final tolerances are set according F8 or 1/100 of mm. Accordingly turning machine and centering cones must be produced at fine precision of 1/1000 of mm. It is also important to stress that in this case the excentricity or axial error can be the most important cause for overall defect of the renovated surface. Therefore it is important to ensure that renovation equipment is properly centered according to the base surface of the bucket bore. Sophisticated axial centering cones (see Fig. 4) are used in order to minimize the set-up errors and to ensure that renovated surfaces will respect all the outlined precision requirements. The design of the catering cone is provided in Figure 8. Where 1 – the main axe, 2 – centering cone, 3 – check nut, 4 – adjustment-fixation ring.

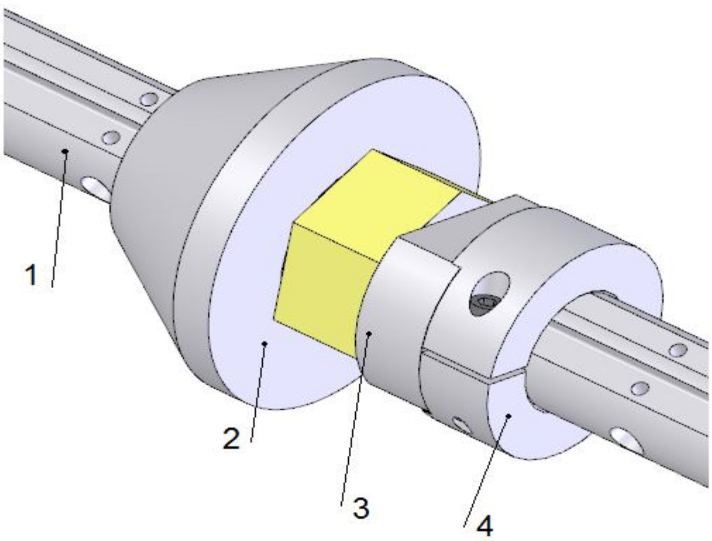

Figure 8 – centering cone on the main shaft

Potential axial error e in these circumstances can be calculated by this equation:

$$e = 0{,}5\left(S + T_D + T_d + T_{dw}\right) \qquad (1)$$

Where, S – is minimal clearance between centring cone and workpiece (bucket bore). S = $D_{min} - d_{max}$. And D_{min} – minimal diameter of the bucket bore, d_{max} – maximal diameter of the centring cone at the contact point – see Figure 9. T_D – tolerance of the bucket bore, T_d – tolerance of centring cone and T_{dw} – mechanical wear of the damaged bucket bore.

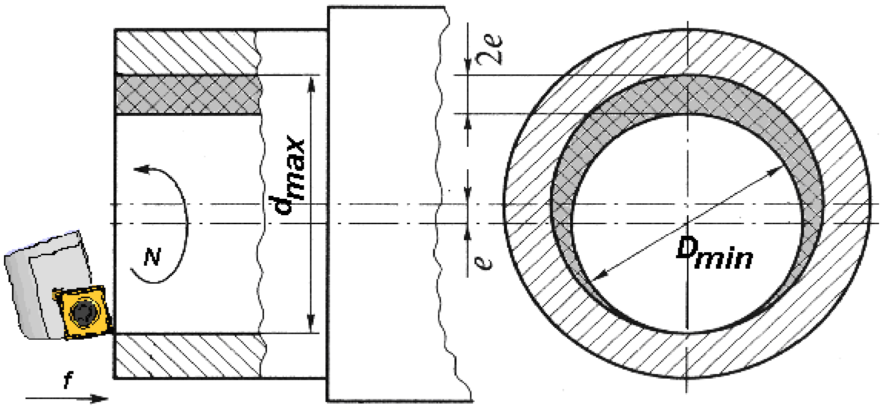

Figure 9 – axial error

Although special attention should be given to the installation of the technological equipment, practical experience reveals that there are many other factors which might considerably affect the end result of the bucket bore repairs. These factors are covered within the next sections.

5. ANALYZIS OF TECHNOLOGICAL OPERATIONS IMPACT TO THE SURFACE INTEGRITY

Surface integrity is a discipline that involves several logical components: surface finish and freedom from cracks, chemical change, thermal damage (e.g. burn, transformation, overtempting), and adverse (tensile) residual stress. Still surface finish is the most important factor for the finishing operations [6]. Finish-turning, which is end operation of this particular technology, is characterized by relatively small depths of cut and light feeds. The depth of cut is normally less than 1.5 mm and feed less than 0.15 mm/rev. The most important factors to observe in this finish turning are: a) dimensional accuracy, b) surface finish, c) tool life.

Dimensional accuracy is mainly a matter of avoiding errors in longitudinal and circumferential form. Errors in longitudinal form result from static deflection of the main shaft and workpiece under cutting forces and thermally inducted stress in the machine. Errors in circumferential form result from run-out of the main shaft and from vibration of the tool or workpiece. The accuracy achieved in this particular case will mainly depend upon stiffness and stability of the machine tool. Extensive studies of dynamic aspects of machine-tool performance confirmed that there are two distinctive types of finish encountered in a turning operation: i) the finish produced by primary cutting edge and ii) the finish produced by secondary cutting edge. The first one usually pertains to surface broaching and form turning, while the second is characteristic of conventional turning using a tool having nose radius. In conventional turning operation the finish left on the workpiece is produced by a secondary cutting edge that is separated from the primary cutting edge by a nose radius (Fig. 10). Use of a secondary cutting edge to generate the finish surface is related with the sequential difficulties:

– Ridges corresponding to the geometry of the tool at its nose and having a pitch equal to the axial feed rate are left behind on the finished surface.

– The undeformed chip thickness goes gradually to zero at the secondary cutting edge, and this causes uncertainty in the geometry of the cut at the trailing edge.

– A concentration of wear occurs at both free surfaces of the cut. The groove thus formed on the end-cutting edge of the tool acts as a forming tool and leaves behind a cold-worked ridge on the surface.

– The metal at the trailing edge of the tool is subject to unusually high normal stress and will flow to the side to relieve this stress. This in turn produces a furrow that contributes to the roughness.

In practical terms in order to perform the analysis of the technological operations impact to the repaired unit surface quality the most important input and output parameters for each of the technological process should be identified (see table 5). This will also help to better structure experiments at the later stage.

Many empirical trials involve the study of the effects of two or more factors. In general, factorial designs are most efficient for this type of experiment. Factorial design implicates that in each complete trial or replication of the experiment all possible combinations of the levels of the factors are investigated. For example, if there are a levels of factor *A* and *b* levels of factor *B*, each replicate contains all *ab* treatment combinations. When factors are arranged in a factorial design, they are often said to be crossed [7].

Input factors *technological process*		Output factors *surface integrity, quality*
Turning regimes *V* *r* *f* *t* Cutting tool geometry	⇨	Surface roughness parameters Dimensional accuracy Tool life

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Other factors Equipment installation accuracy BUE System stability		
Welding Gas supply Electrical current *A* Voltage *V* Wire feed speed f_{wire} Welding nozzle angle Welding wire material (chemical composition) Welding speed V_{weld}		Material properties (chemical) Hardness Tensile strength Min yield strength Impact resistance

Table 5 – general model of the technological system

The effect of a factor is defined to be the change in response produced by a change in the level of the factor. This is frequently called a main effect because it refers to the primary factors of interest in the experiment. The aforementioned experiments analysis methodology should be kept in mind describing technological operational regimes impact to the surface quality. It shall be deployed during experimental work itself and when choosing the adequate analysis software. For both turning operations (rough and finish) the following principal correlations should be determined - table 5.

5.1. Cutting tool geometry

Its impact to the surface roughness can be calculated taking into account tool nose radius r of the cutting insert and side cutting edge angle and c) end cutting edge angle. Figure 10 shows view of a turning operation with ridges left behind on the finished surface, so called feed marks.

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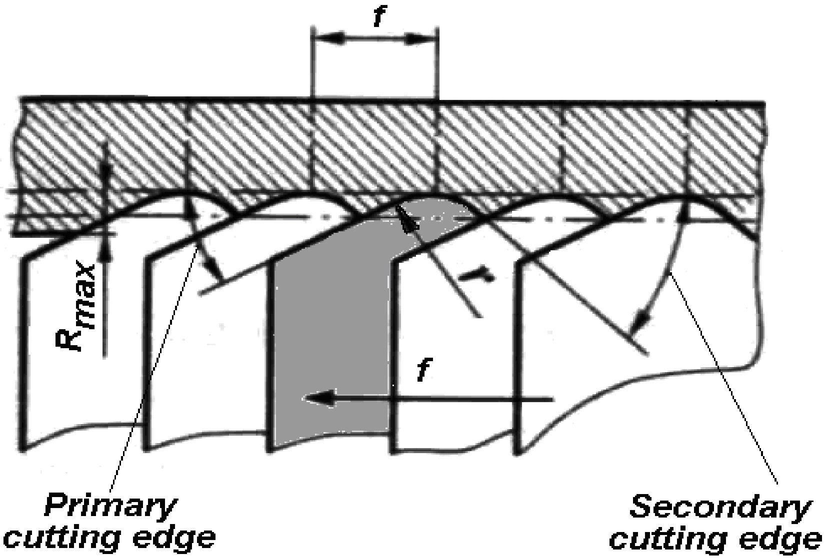

Figure 10 – cutting insert radius impact to surface roughness

Figure 12 illustrates the view of the tool tip (insert) which is defined in terms of three quantities: a) nose radius r, b) primary (side) cutting edge angle – α_c and c) secondary (end) cutting edge angle – β_c.

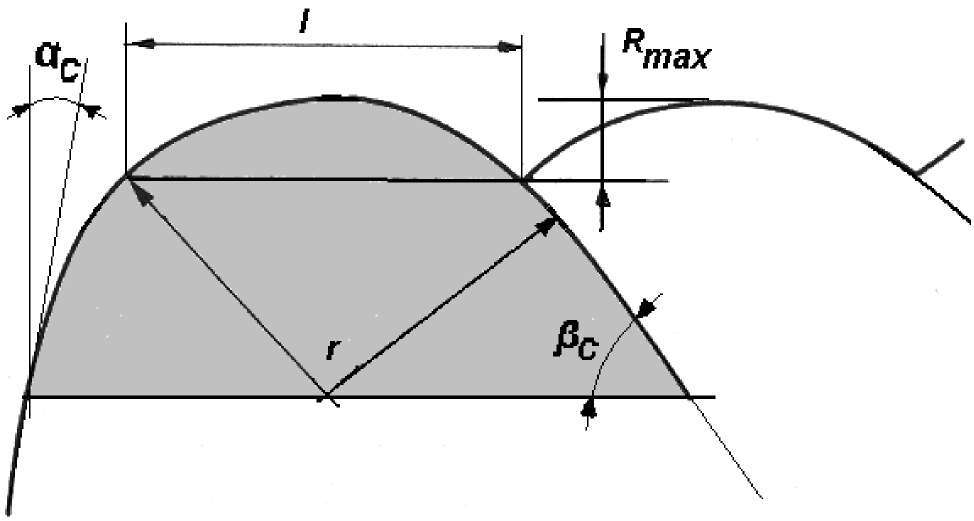

Figure 11 – Top view of the cutting tool tip

According to Milton C. Shaw (2005), when the nose radius is large enough and the feed is very small, the surface will be generated by the nose radius alone [5]. In this case maximum peak-to-valley surface roughness can be calculated by the following equation:

$$R_{\max} = r - \left(r^2 - l^2/4\right)^{1/2} \cong \frac{t^2}{8r} \qquad (2)$$

This equation can be transformed into non-dimensional form

$$\frac{R_{\max}}{r} = \frac{1}{8}\left(\frac{t}{r}\right)^2 \qquad (3)$$

The equation 3 is valid as long as this condition is respected:

$$0 < \left(\frac{t}{r}\right) < 2\sin\beta_c \qquad (4)$$

For larger feed values (this particular case) all factors should be taken into account: *l*, *r* and α_c, β_c must be brought in:

$$R_{\max} = \frac{l}{\tan\alpha_c + \cot\beta_c} - \frac{r\cos\left(45 - \frac{\beta_c}{2} - \frac{\alpha_c}{2}\right)}{\sin\left(45 - \frac{\beta_c}{2} + \frac{\alpha_c}{2}\right)} + r \qquad (5)$$

or in non-dimensional form:

$$\frac{R_{\max}}{r} = \frac{\frac{l}{r}}{\tan\alpha_c + \cot\beta_c} - \frac{\cos\left(45 - \frac{\beta_c}{2} - \frac{\alpha_c}{2}\right)}{\sin\left(45 - \frac{\beta_c}{2} + \frac{\alpha_c}{2}\right)} + 1 \qquad (6)$$

This equation is valid when:

$$\frac{l}{r} > \cos\alpha_c + \sin\beta_c + \left(\cos\beta_c - \sin\alpha_c\right)\cot\beta_c \qquad (7)$$

These equations are clearly illustrating tool tip radius and maximum peak-to-valley surface roughness influence to ten-point mean roughness, which in this paper is abbreviated with R_{max}. However, in industrial practice ten-point mean roughness parameter R_z is used more than others. Although, this will change soon and new 3D surface texture parameters will come into force, meanwhile an empirical equation for prognosis of R_z values can be used:

$$R_z = \frac{f^2}{8/r} \qquad (8)$$

where *f* – is feed mm/rev and *r* – cutting insert radius. In practice usually cutting inserts with *r* 0.5 mm are used for the final operation, and usually delivering requested results.

5.2. Turning feed f

Is crucial factor which affects the end surface finish, not because of geometrical properties of the working part of instrument but also thanks to elastic and plastic behavior (deformations) of the surface layer. When *f* increases these deformations augment as well and this brings increase in the surface roughness – see Figure 12. According to this correlation the optimal surface roughness values could be obtained staying within reasonable intervals of feed between 0.05 and 0.12 mm/rev [8]. This is feasible with the existing in-situ technological equipment and should be considered as a technological recommendation, when possible.

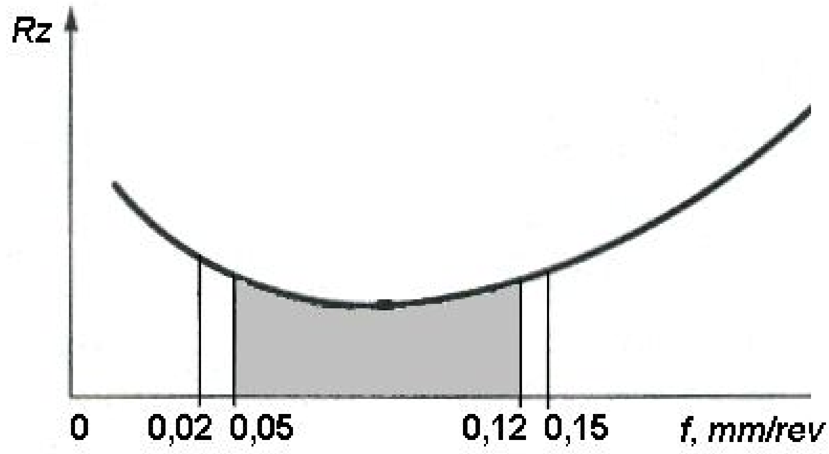

Figure 12 – Feed impact to R_Z

5.3. Cutting speed V

Is one of the most important technological parameter which strongly influences the finish result produced. The finish for turning with the lower speeds is very poor, particularly that produced by the primary cutting edge. Much better roughness is obtained at higher speeds, particularly in the case of surface generated by the primary edge. The finish obtained by use of a secondary cutting edge is seen to approach that corresponding to the feed marks at a high cutting speed. Illustrative example of V impact to the surface roughness parameter R_z – ten-point mean roughness is shown in Figure 13.

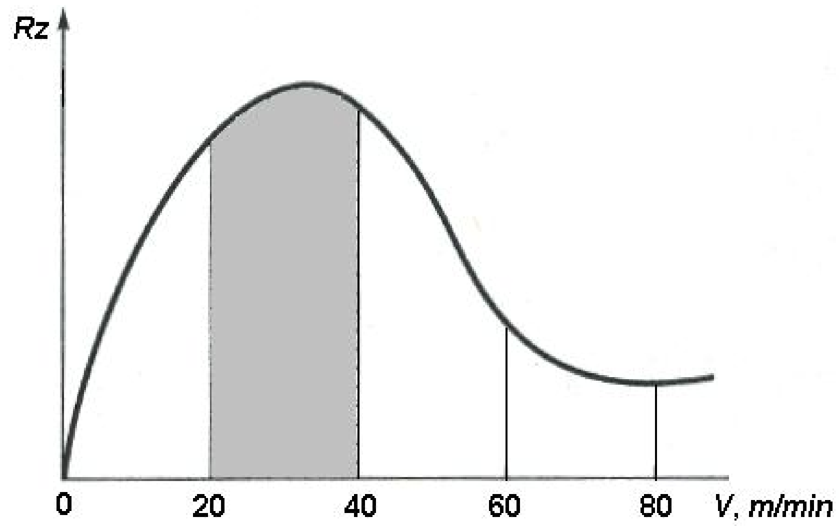

Figure 13 – Cutting speed impact to R_Z

Cutting depth *t* will have only marginal influence to the surface integrity in the system stability is sufficient [8].

5.4. System stability

The machining system can deviate from designed geometry in two general ways – static deflection leading to inaccuracy of the machined part or dynamic instability leading to periodic errors such as waviness and roughness. Both deflections should be considered as a potential risk for the particular technology and evaluated.

Static deflection may arise due to lack of stiffness of the machine structures (e.g. bearings), deflection of workpiece or tool, differential thermal expansion, or dimensional instability of materials due to changes in residual stress or due to a density change accompanying a structural transformation. Dimensional accuracy of the machine tools may be improved by increase the precision of components or by correcting residual inaccuracies. See accuracy requirements analyzes above.

Dynamic instability in which there is cyclic relative motion between tool and workpiece is of two tapes – forced vibration and self exercised vibration. A forced vibration results when a cyclically varying external load has a frequency that is close to one of the natural frequencies of the system "tool-workpiece-machine-device". Vibration may be reduced by:

– Elimination of the cyclic exciting forces;
– Avoiding the coincidence of frequency of exciting force and natural frequency;
– Increased stiffness.

Currently the surface roughness parameters are regulated by ISO standards that characterise the surface roughness of a workpiece by means of two dimensions (2D). There are certain national standards used by industrially developed countries and, on top of those, there is a well established practice regarding these measurements in all the sectors of production engineering. Today USA has found itself in the lead position by having already developed its own national surface roughness standard ANSI/ASME B46.1-2002: Surface Texture, Surface Roughness, Waviness and Lay [9]. Previous standards and technical specifications were based on surface roughness measurements only in 2D, done by profilometers using the contact method. In most cases the industrial measurement equipment is still based on 2D profiles contact gauges and subsequent subtraction of surface roughness parameters from the linear readings [10].

However, every workpiece is a spatial object and, to obtain complete measurements, such object has to be analysed and mathematically overlooked as a 3D object. Topographical or texture method of the surface analysis instead of the usual surface cross-cut roughness approach, is describing the particular surface sufficiently and completely, reflecting real surface conditions. Thus it is an absolutely new concept that differs from the existing surface definitions canonised by the industry. 3D parameters are calculated on the entire surface (in a plane) and no more by calculations derived from the base lengths (cross-cuts), as is the case for 2D parameters [10, 11]. For example in two dimensional model arithmetical mean roughness – *Ra* is calculated using this formula:

$$Ra = \frac{1}{l}\int_{0}^{l} f(x)dx \qquad (9)$$

where l – is length of examined profile in cross-section.

Current surface roughness indicators measurement and calculation practice will be principally changed. The upcoming ISO 25178 standard for Geometric Product Specifications – surface texture is the very first international standard to provide detailed specification and measurement techniques of a 3D surface micro-topography [12]. Spatial surface texture parameters, their measuring and processing rules will also be covered. It is important to underline that the draft standard in question is based on non-contact measurement methods. Some of these methods are already used in the instrument production industry.

6. 3D SURFACE ROUGHNESS PARAMETERS

It is important to note that 3D surface texture standard ISO 25178-2 currently is in the "Approval stage". Although it is difficult to estimate when the new requirements might become mandatory, there is no doubt that the industry shall adapt to the ISO 25178 as soon as possible.

Taking into account the aforementioned considerations, the principal question is: what to do when the manufacturing engineer, instead of seeing the familiar Rz in the clients' drawings, is surprised by a Sq? Although it is not a completely precise technique and cannot be applied in all cases, a simple mathematical extrapolation of 2D method can be used for the conversion of some indicators from 2D to 3D. The following equation can be used to obtain the value of the root mean square height of the surface [13]:

$$S_q = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy} \qquad (10)$$

where: A – definition area of the reference surface in mm^2;

$z(x,y)$ – ordinate value – height of the scale limited surface at positions x and y.

The same approach can be used for the calculation of many other surface roughness indicators. To obtain 3D values, the general principle is to break down the observed surface to several separate profiles. These profiles can be obtained by using the existing 2D surface roughness measuring devices. The analysed surface has to be divided into a number of separate profiles. Practice shows that 10 profiles with a measuring trace length $l = 4 \div 5$ mm is a sufficient number, which allows to obtain reliable results. The following equation can be used. Example is given for S_a – arithmetical mean height of the surface.

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M} R_a(i,j) \qquad (11)$$

Where: M – number of measurements within a single profile;

N – number of profiles examined;

i – the examined profile;

j – the measurement within the profile.

7. CONCLUSIONS AND FUTURE WORK

A competitive repair company should possess operationally acceptable, quantitatively and qualitatively adjustable technologies, where technical solutions as well as requirements are integrated and interoperable. In-situ renewal technology of the backhoe bucket bores is such technical solution and this article outlines some problematic issues of this novel repair technology. Description of the renewal operations is commenced with installation of the turning-welding machine directly on the damaged backhoe bucket. The initial installation (base), which is principally important for all the successive technological manipulations, can encounter the following difficulties: a) the base surface is substantially damaged; b) setup or installation error; c) damaged, worn out equipment. In order to minimize the installation error e, an equation for its calculation is provided. This might be used in engineers' daily work, when performing repairs with the given equipment.

Subsequent turning operation has to face irregular allowance for machining, interrupted contact with surface and non-homogenous strain hardening. These factors have a significant influence to the turning operation, resulting in uneven and irregular turning pattern. Hence it is very important to determine the actual load effects on renovation equipment and its particular critical parts.

For the built-up welding the corresponding technological regimes together with the appropriate gases and welding wire are provided – these can be used in daily work too. However, these values are only result of initial considerations, and shall be experimentally tested in the further researches.

In the final turning operation, where the product receives its working dimensions and surface properties, strong interactions were observed among turning regimes. Most influential technological parameters were identified: cutting tool geometry (insert radius and main angles), turning feed and speed. Their impact to the surface integrity and end quality has been established.

The initial results reveled in this paper are forming an essential fundament for the in-depth renovation technology research. Actually this analysis is solid basis for understanding of existing problems and flags the way forward. Following principal considerations can be stressed for the in-situ renovation operations in general:

– Rigidity and stability of tool-workpiece-machine-device system;

– Limitations on speed, feed, or depth of cut;

– Whether new or worn tool is considered.

A further study involving surface roughness characteristics should be performed taking into account the new surface roughness 3D parameters stipulated by upcoming ISO 25178-2 surface texture standard.

This article identifies magnitude of the problems which are encountered analyzing in-situ renewal technology for the backhoe bucket bores, and clearly outlines the further research scope and general trends. Series of carefully prepared experiments followed by factorial analysis using SPSS or Minitab are already foreseen and will use the results of this article for the upcoming work.

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