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Article

The use of a measuring arm with a laser scanner for analysis and support of regenerative surfacing processes of forging dies

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Abstract: The article presents the results of research conducted in order to develop the technology of regenerative surfacing of forging dies. The selected example shows how the use of a measuring arm with a laser scanner can be used to support the regeneration process. The tests were conducted in industrial conditions of a forging die. The analysis of the regeneration process was carried out at each of 4 stages: after wear in the forging process, after initial machining, after regenerative surfacing and after final machining. It has been shown that scanning can be used to develop programs for mechanical pre-treatment, to measure the volume of padding welds, to determine the amount of finishing allowance, to verify the effectiveness of the surfacing process and to control the quality of the die before the forging process. The obtained results confirmed the effectiveness of the regeneration carried out. In terms of performance, it has been shown that too much padding weld's material is a machining allowance. For this reason, the treatment is time and energy consuming and about 68% of the padding weld's material is waste or chips. The analysis showed the possibility of saving up to 45% of the weld metal material by using reasonable allowances of smaller thickness. These results indicate the need to modify the regeneration technology and the legitimacy of using robotic surfacing, which can provide greater precision and repeatability in the layingof padding weld’s beads. The next stage of research will be robotization of the analyzed forging die regeneration process using WAAM technology.

Keywords: surfacing; regeneration; forging die; wear; scanning

Introduction

The wear of tools in forging processes has long been the subject of research in many scientific centers. These studies concern, among others wear mechanisms that destroy the surface layer of tools, and various methods to increase wear resistance. In recent years there has been a clear increase in interest in this subject. The observed trend of interest in new methods to increase durability is mainly due to the development of research conducted at the micro and nano scale, which is due to the greater availability of electron scanning microscopy, atomic force microscopy, various methods of detection of chemical and phase composition. As a result of the dissemination of these methods, new chemical compounds, coatings and layers were discovered. New materials with better performance properties have great potential for use in many fields of technology [1,2].

One of the most commonly used methods for creating layers with increased wear resistance is surfacing. Most often, in order to regenerate used forging dies, regenerative surfacing is used, which involves removing a layer of material from the surface and applying a new layer made of weld metal with better performance properties. The development of material engineering has also brought the possibility of preventive surfacing, in which even new tools are surfaced with material with better properties to increase its wear resistance. There are many examples which confirm that the durability of forging tools can be effectively increased by surfacing [3÷6]. This is the most economical method of making tools, because it enables the repeated use of the same matrix, which can reduce the average cost of tool making by several to several dozen percent.

Currently, the most popular methods of surfacing of forging tools, including regenerative surfacing, are surfacing with coated electrodes, self-shielding flux-cored wire, sub-arc (electrode wire or electrode tape), MIG method (solid wire or flux-cored wire), MAG method (solid wire or flux-cored wire) and the TIG method. Shape of the tool, thickness of the layer and the required quality of the padding weld usually decide about the application of a given method [7]. Regardless of this, the decisive impact of the durability of tools subjected to surfacing is the proper selection of the surfacing material, which ensures improved resistance to abrasive and adhesive wear, thermo-mechanical fatigue, plastic deformation and corrosion. Therefore, the majority of recent research focused on the selection of dedicated materials forming the padding weld to the base material from which the tool was made.

The latest methods of surfacing also used in regenerative surfacing include powder surfacing. This process involves the use of an HPDL diode laser beam to fuse powder in an additional gas shield and at the same time melt the substrate metal, which when melted together form a padding weld. The additional material fed to the surfacing area melts at a very high speed, resulting in a thin layer of thoroughly melted material with the ground melted to a very small depth. The thickness of the molten layer can be changed in the range of approx. 0.1 mm to 2.0÷3.0 mm, and the face of the padding weld is even and smooth. The final machining allowance does not exceed 0.05÷0.10 mm [8]. The molten padding weld's metal solidifies in an inert gas shield at a rate of 10 °C/s. As a result, its structure has very high metallurgical purity and is very fine. However, this technology is not yet well mastered and requires further research. As in the case of traditional welding methods, the type of padding weld material used has a decisive impact on service life [9].

As mentioned, in the regeneration process proper tool durability is very important with relatively low costs of its production (or regeneration). The cost of regeneration is mainly due to the amount of weld metal used, energy and shielding gas consumption, as well as employee engagement time. The cost of regeneration is also significantly affected by highly energy and time consuming mechanical machining carried out after surfacing in order to give the final shape of the die working pattern. Mechanical machining of allowances left in the surfacing process is extremely difficult due to the uneven and unique padding weld geometry, which forces caution and limiting the feed of cutting tools. Leaving excessive allowances also extends the time and cost of machining, which sometimes exceeds the costs of the surfacing process itself. These problems lead to the search for new solutions especially in the field of welding robots and manipulators.

The current development of control systems enables robotization of the surfacing process. Robotic surfacing allows obtaining repeatable geometry of pad welds, whose machining is much easier to program. In addition, the use of welding robots improves the precision of surfacing, which reduces excessive oversize and brings further savings. Finally, robotization allows for greater efficiency and significantly reduces the cost of the regeneration process.

In this work, an attempt was made to analyze a selected dies regeneration process in which key technological aspects were selected from an economic point of view. The research was carried out on representative tools for which the entire regeneration cycle was analyzed. Process analysis conducted in terms of technological changes, especially robotization of the surfacing process. Modern measurement tools based on coordinate metrology were used to analyze the process.

The intensive development of measuring techniques in recent years gives new opportunities in the context of mobile metrology. Currently, portable CMM measuring machines provide measurement accuracy in the tenths or even hundredths of a millimeter depending on the measuring range [10,11]. Such accuracy is sufficient for most applications in the field of measuring the geometry of plastic forming tools.

Among the various mobile solutions, such as hand-held measuring probes with tracking systems, portable column, bridge or portal modules, coordinate manipulator solutions proved to be convenient in terms of dies geometry measurements. Such a manipulator allows measurements to be made in a working environment without the need to transport dies. The weight of the measuring arm depends on the measuring range but in most devices does not exceed 10 kg. From here it can be moved and handled by one employee. In addition, mobile solutions save time needed for measurements and eliminate most logistical problems related to the transport of dies. This has a direct impact on the economic aspect of the geometry control activity.

In addition, the use of the measuring arm allows the use of different measuring heads depending on the needs. They can be capacitive, contact or other sensors as well as optical systems using a laser beam [12]. Optical solutions allow you to further increase the application flexibility of mobile measuring systems based on the use of coordinate measuring arms. They create, therefore, the possibility of creating mobile non-contact measurement stations using the properties of laser light such as monochrome light beam interference.

For these reasons, it was decided to use a mobile measuring system consisting of a coordinate arm equipped with a laser scanner to assess the state of dies in laboratory conditions.

Materials and methods

The forging die regeneration selected for testing was carried out in accordance with the technological instructions developed for this purpose. First, the die was cleaned by sanding the dirt formed during forging. Then, an analysis of the amount of wear and identification of damage such as cracks and chipping was carried out. To measure the amount of wear for tools with relatively simple shapes, basic measuring tools are used, while for more complex patterns, specially prepared gauges are often used. The analysis of wear and identification of damage is very important because on this basis you can determine the scope of necessary machining. In the case of the analyzed die, the pattern on the entire surface was reduced by milling by min. 5 mm, while in the area of the sternum and in places where higher wear has been identified up to 20 mm. All beams in the working pattern were prepared for a minimum of R6. The die prepared in this way was subjected to surfacing. The surfacing process was carried out in accordance with the Welding Procedure Specification (WPS). The instruction defines the way of laying beads during surfacing in the analyzed die and parameters of the surfacing process. For surfacing, a binder with the trade name Welding Alloys – Robotool 46 was used. The instruction assumes that in the event of a crack on the corners of the die, use a preliminary bead using a binder with the trade name Castolin XHD 646, method 111 (coated electrode).

The analyzed die immediately after surfacing was subjected to annealing in an oven at 450 °C for 4 hours, then slowly cooled. After this operation, the die was mechanically finished by milling in accordance with the technical documentation. It should be emphasized that mechanical treatment after regeneration takes a lot of time and is very difficult. Unevenly arranged weld beads, made of high hardness materials, are very difficult to process. Frequently, the variable geometry of the processed material causes overloading of milling heads, plates breakage, premature damage and excessive wear. This necessitates limiting feeds on machine tools, which in turn leads to unusually long machining times.

The adopted methodology of dies regeneration and current geometry control consisted of several stages, with the most important assumption being to ensure precise shape measurement at each stage of regeneration. Based on this assumption, the regeneration process plan was supplemented with a die geometry measurement with a laser scanner. A predefined set consisting of a coordinate arm Romer Absolute Arm 7520si equipped with an integrated RS3 laser scanning head was used for testing the quality of dies, while the GOM Inspect environment and the PolyWorks measuring environment were used to handle the whole. The idea of supporting the regeneration process is schematically presented in figure 1. It presents the adopted methodology of using laser scanning to support the process of forging dies regeneration.

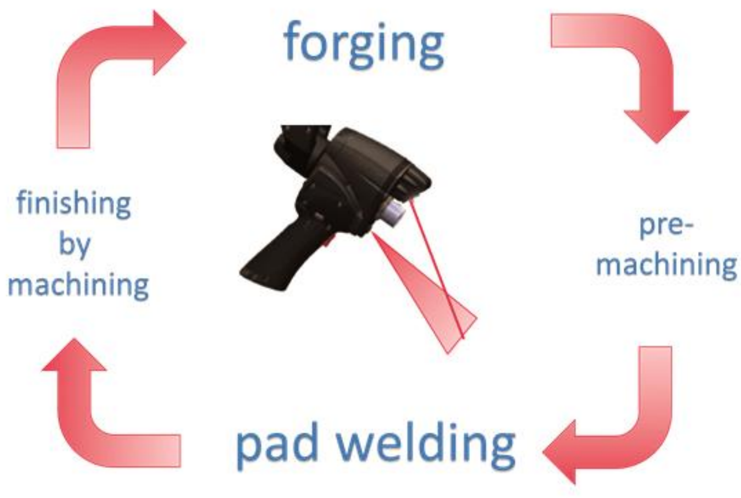


Fig. 1. Schematic approach to the methodology for supporting the forging die regeneration process by laser scanning

Below are the operating parameters of the set used for measuring and data acquisition [13].

Technical specification of the Romer Absolute 7520si arm:

– measuring range ....2.0 m / 6.6 ft.
– positioning repeatability .... 0.023 mm / 0.0009 in.
– volumetric measurement accuracy..± 0.033 mm / 0.0013 in.
– scanning accuracy with the RS3 head kit ....0.058 mm/0.0023 in.
– unladen weight of the arm ....8.6 kg / 19.0 lbs

Technical specification of the integrated RS3 scanning head:

– maximum data acquisition frequency..460 000 pkt/s
– scanning line resolution ....4600 pkt
– scanning line refresh rate ....10 Hz
– scanning line length...46÷85 mm. dia. 65mm
– working range (distance from the head) ....150 mm ± 50 mm
– minimum distance of the measuring points ....0.014 mm
– scanning accuracy ....2 sigma / 30 μm
– weight ....340 g
– working temperature.. 5÷40°C (41°÷104°F)

The manufacturer's specification procedure was carried out in accordance with ASME B89.4.22-2004 [14].

The first stage in the dies regeneration process was measuring the geometry of the used dies. The kit shown above was used for this purpose. The goal at this stage was to obtain information about the condition of the dies damage for subsequent machining. Determining the depth of the defects allowed the assessment of the amount of material that should be removed, damaged as a result of wear processes present during forging.

The next stage was the machining of the die by milling the work pattern to a depth of min. 5mm or below the depth of the detected cavities. The geometry obtained was again measured using the coordinate set used. The purpose of these measurements was to determine the volume of material needed to reproduce the die's geometry.

The next stage was the dies regeneration by surfacing, after which the surface geometry was also measured. The data obtained at this stage also enabled an assessment of the padding weld's continuity and whether a correction is needed to eliminate potential underfillings. Volumetric calculations were carried out in the PolyWorks environment. It is an environment integrated with the measuring system that allows us to compare the 3D CAD model with the model generated on the basis of data obtained from laser scanning. PolyWorks Inspector enables workpiece inspection, in particular the identification and calculation of the discontinuity volume of the workpiece material after machining using the CAD model as the reference value.

The detail after surfacing and measurements along with the discussed calculations has been prepared for mechanical machining. At this stage, the die's surface was milled until the new geometry was restored. Then, according to the adopted methodology, re-scanning was performed, which at this stage was aimed at determining the volume of material lost for finishing by milling. Similarly to calculations of the volume of material needed for surfacing, CAD/CAM PolyWorks environment was used at this stage. In addition to calculating the machining allowance volume, the CAD/CAM environment was used at this stage to verify the final die geometry before starting the forging process.

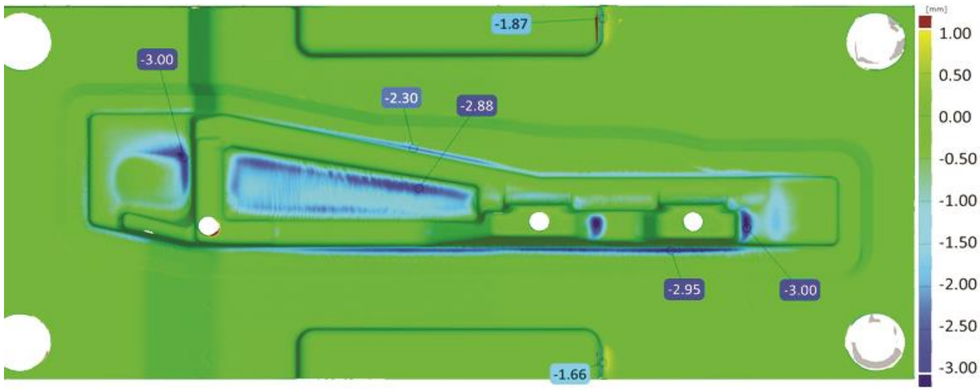
In addition to the effect described above, which is the support of the existing regeneration process, the purpose of the above analyzes was to develop robotic regenerative surfacing technology and to analyze the profitability of implementing such technology. This analysis included an estimate of profit as a result of limiting the volume of allowance generated in the regeneration process. Robotic surfacing is to improve the precision and repeatability of the padding weld beads that are being laid, which is to reduce the allowance and shorten subsequent machining. The achieved savings can be important not only in the context of the economics of the dies regeneration process but also in the context of creating machining stations with low energy consumption and, as a consequence, environmentally friendly.

Results

As mentioned in the "Materials and methods" section, the studies covered the full forging dies regeneration cycle. This part presents the results of analysis of the used dies and after subsequent stages of its regeneration by sufacing, which included mechanical treatment before sufacing, sufacing and mechanical treatment after sufacing. Potential possibilities of using scan results to assess wear and selection of mechanical machining programs before sufacing, assessing the efficiency of the sufacing process, measuring the volume of weld metal used for the construction of padding welds, measuring the thickness of the machining allowance after sufacing and measuring the volume of the allowance that is lost as a waste have been demonstrated. The results obtained were also used as input data for the planned robotization and modernization of the entire regeneration cycle.

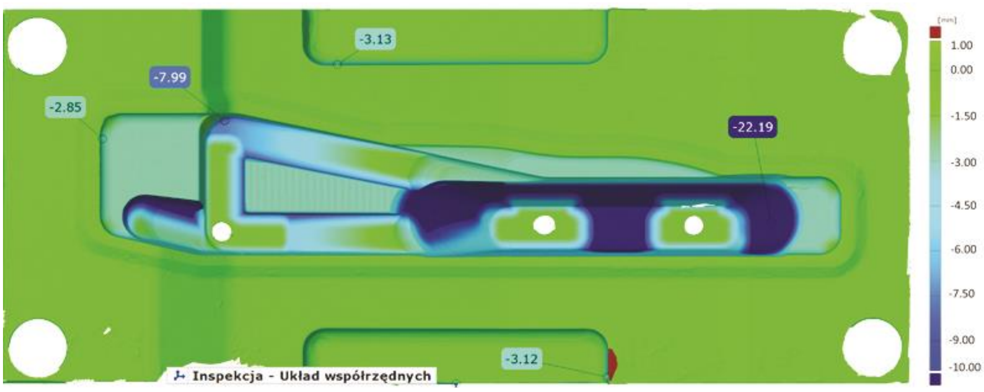
The used die analysis and selection of machining parameters before the surfacing process

First, an analysis of the used die was carried out, which was sent to the regeneration process. The analysis was made by comparing the scan of the used die to the surface of the CAD model. The result of the comparison in the form of a color deviation map is shown in figure 2a. From the presented data it can be concluded that wear occurs in selected places and reaches a value of up to 3 mm. To determine the type of wear, figure 2b also includes a photo of the surface of the die being analyzed. Grooves characteristic for abrasive wear are visible on its surface. Wear occurs in the central part of the die, on rounded corners and edges, which are located around the bridge and in many other parts of the die's pattern. The extent of wear and significant depth of defects is the basis for carrying out regenerative surfacing over the entire surface of the working pattern. Therefore, mechanical machining covering the entire working surface was proposed. A layer thickness of 5 mm was adopted as the minimum amount of material necessary to remove due to damage. However, due to the difficulties in machining complicated shapes, the machining program has been simplified to simple geometries resulting from the shape of the tool and the realizable path of the milling head. The effect of such simplification is the local removal of a layer of material with a much greater thickness, reaching up to 20 mm. However, the average thickness of the removed layer reaches about 5÷6 mm, which was proved by comparing the die's scan after machining to the CAD model (Fig. 2c).



(a)

(b)



(c)

Fig. 2. The die used before the regenerative surfacing process: a) scan of the die's surface compared to the CAD model; b) View of the surface of the used die; c) surface scan of the die after machining before surfacing

Analysis of the efficiency and effectiveness of the regenerative surfacing process

In order to assess the effectiveness of the surfacing process in the context of the efficiency and degree of filling of the assumed geometry, a comparative analysis of the scan of the die made before surfacing was carried out in regard of the scan made after the surfacing process. The results of this comparison are shown in figure 3a.

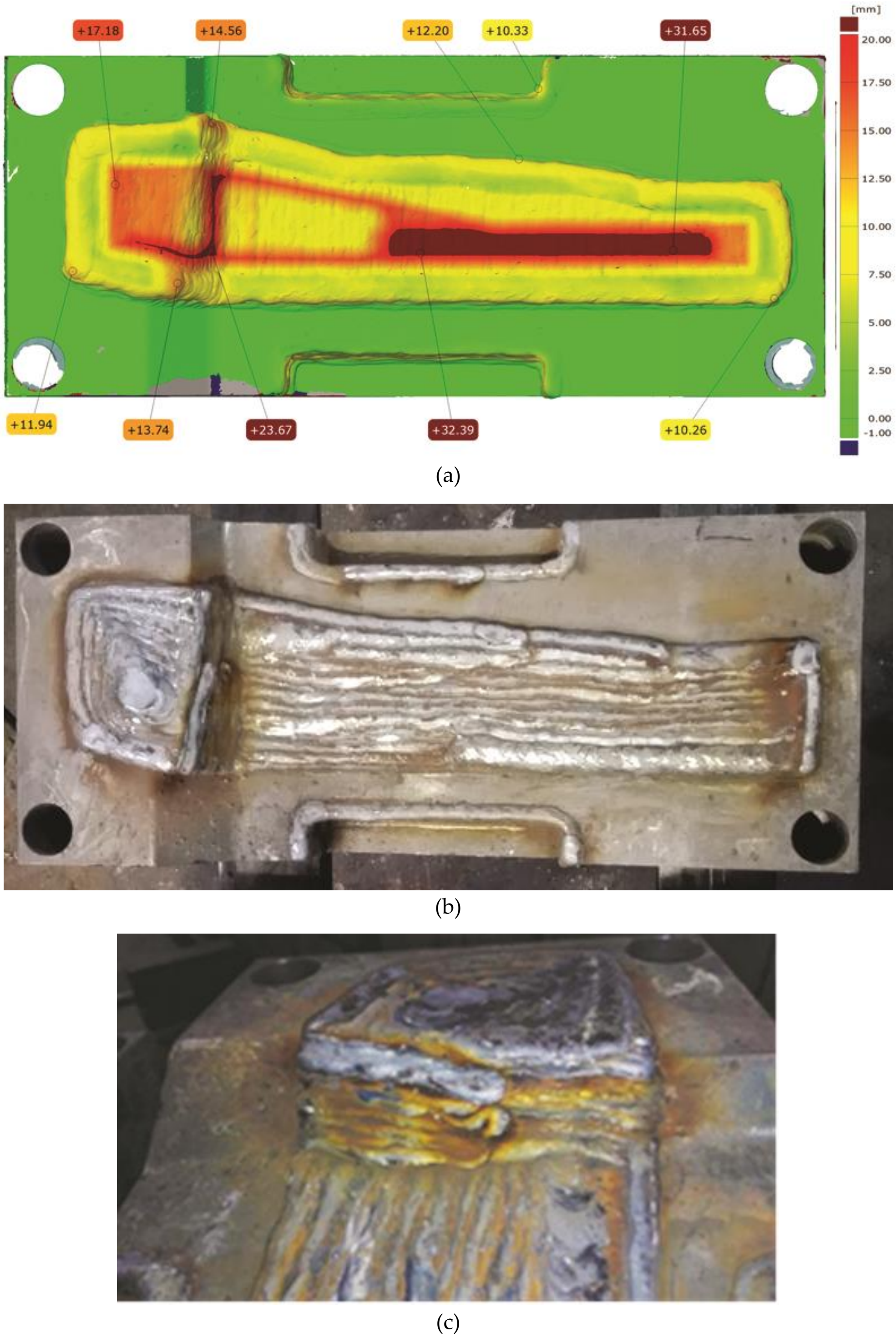


Fig. 3. The die after the regenerative surfacing process: (a) a scan of the surfaced die's surface compared to the scan before surfacing; (b) view of the surface of the surfaced die; (c) a detailed view of the padding welds

Comparative analysis of the die's scan before and after the surfacing revealed the thickness of the surfaced layer, which is in the range of 5÷32 mm. It is a padding weld made of many layers whose arrangement on the surface is visible in figures 2b and 2c. Figure 2c presents a detailed view that reveals how to build padding welds in individual layers in the downhand (PF), lateral (PB) and vertical (bottom up) (PF) positions. The measured thickness of the surfaced layer seems too large and suggests excessive wear of the weld metal. Surfacing in this case was done in a way that the interior of the pattern is filled with material until a smooth surface is obtained. Such surfacing is very energy- and material-consuming and in many places the allowances could be smaller. In order to assess the possibility of saving material, figure 4 compared the scan of a surfaced die before and after machining.

The deviation measurement (Fig. 4) indicates a considerable allowance, with an average thickness of approx. 10 mm, which in some places exceeds even 20 mm. From a technological point of view, an allowance with an average thickness of 3 mm is sufficient, which ensures that surface contaminants will be removed during machining and minimizes the risk of underfilling in the die's pattern. To quantify the amount of allowance, volume measurement was used in the PolyWorks measurement program. The volume of the entire padding weld and the amount of allowance that was removed during machining were measured. The volume of the "standard" allowance with an average thickness of 3 mm over the entire die surface was also calculated. The results of the calculations are presented in table I.

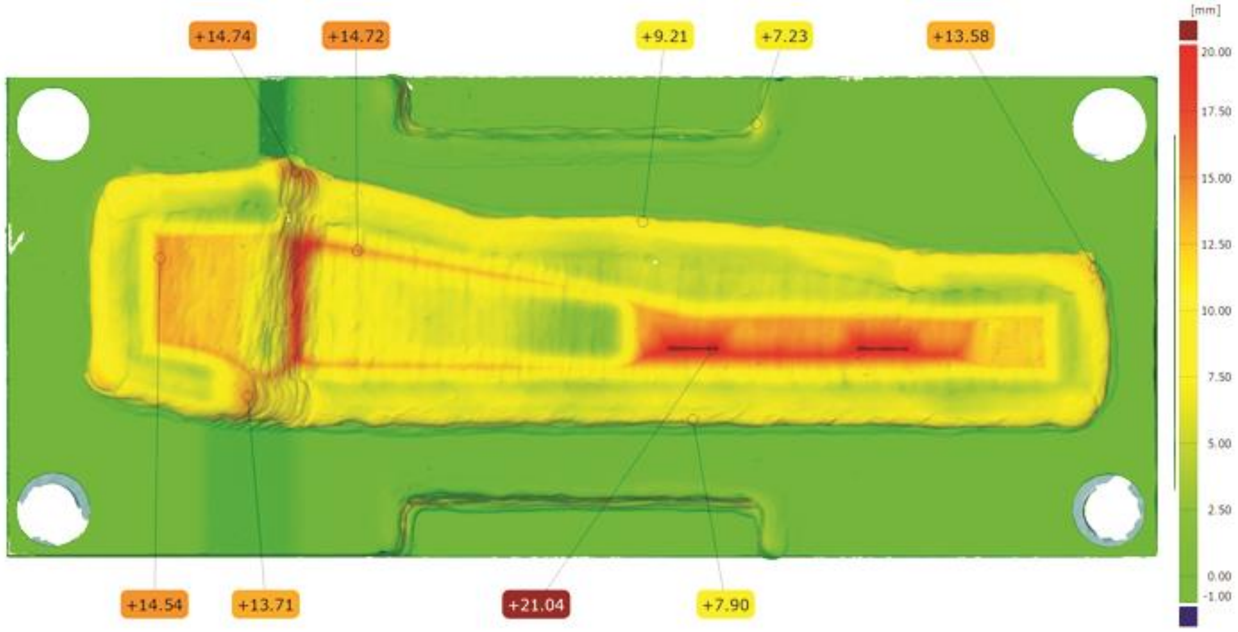


Fig. 4. Comparative analysis of the surfaced die before and after machining

Table I. Results of the measurements of the padding weld's volume and allowances

Physical size	The entire padding weld	Choosing before surfacing	Allowance for machining (A)	Optimal allowance (B)	Material loss in current technology (A - B)
Volume [mm³]	1 236 058	399 564	836 494	278 794	557 700
Volume [%]	100[1]	32	68		45
Mass [kg]	9,64	3,08	6,56	2,18	4,34

[1] The padding weld is made in current technology, which fills the volume selected before surfacing and creates an allowance. As such, it represents 100% of the additional material used.

Figure 4 presents images from the PolyWorks program, which shows how to measure the volume between the surfaces of scans before and after surfacing (Fig. 5a), before and after machining (Fig. 5b), and measuring the volume of the optimal allowance with an average thickness of 3 mm assumed relative to the regenerated die on the whole working surface of the forging tool (Fig. 5c).

The results of the measurement of the padding weld's volume and allowances presented in table I showed that the analyzed regenerative surfacing technology uses too much allowance for machining. In this case, as much as 68% of the surfacing material is useless waste in the form of chips, which requires many times longer costly and energy-intensive mechanical machining. Table I also includes calculations indicating the possibility of limiting this allowance to a layer with a thickness of approx. 5 mm (Fig. 5c). In this solution, the material saving will be about 45% in the entire padding weld. In order to implement this solution, it is recommended to change the surfacing technology, especially in the scope of choosing a more precise surfacing method, optimizing the method of laying the padding weld's geometry, but also using robotic surfacing instead of manual.

Verification of the die after the regeneration process

To assess the efficiency of surfacing and machining, the die was also scanned after final machining and compared to the CAD model. The result of this comparison is shown in Figure 6a. Figure 6b shows a view of the machined surface of the tool under analysis.

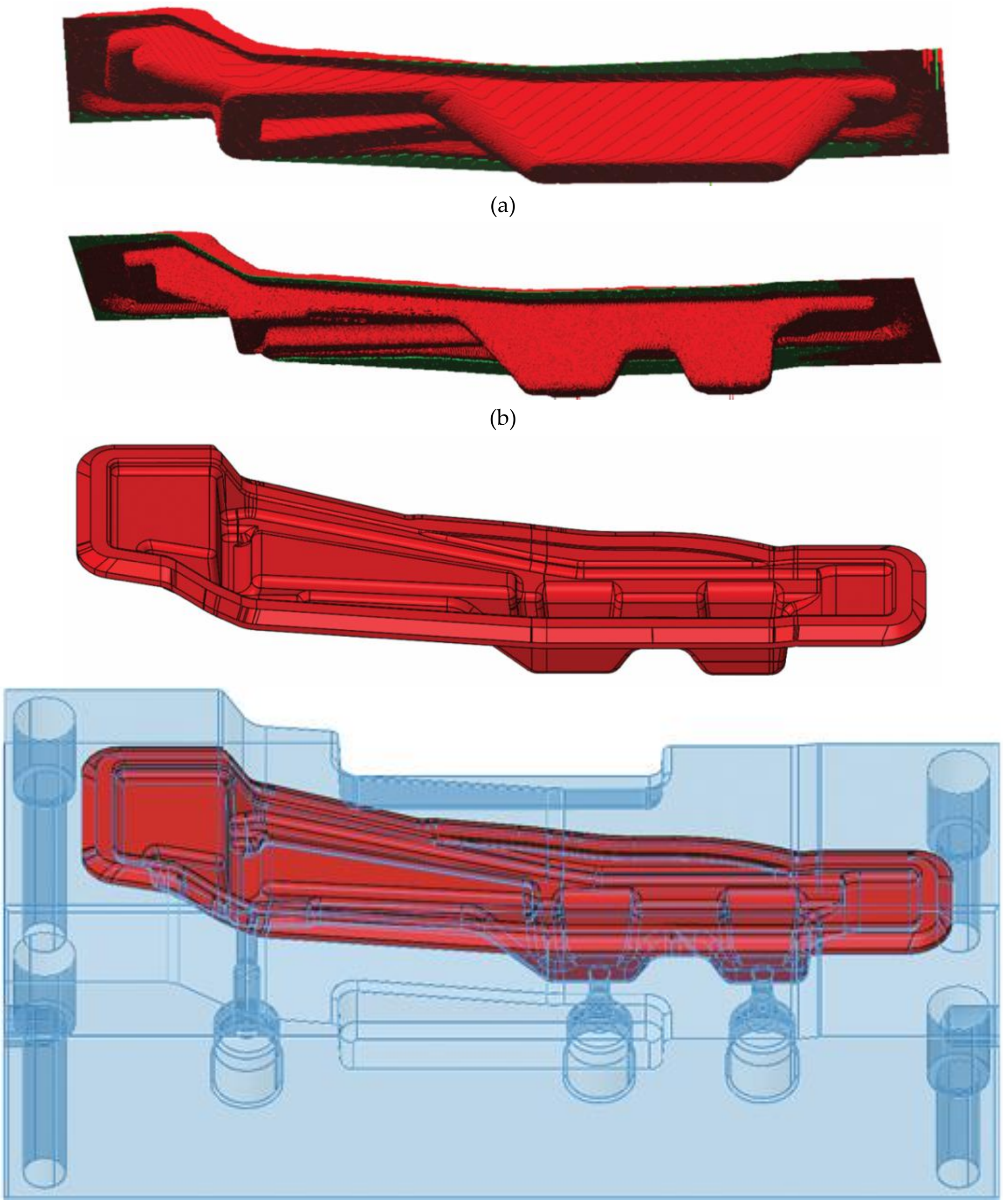
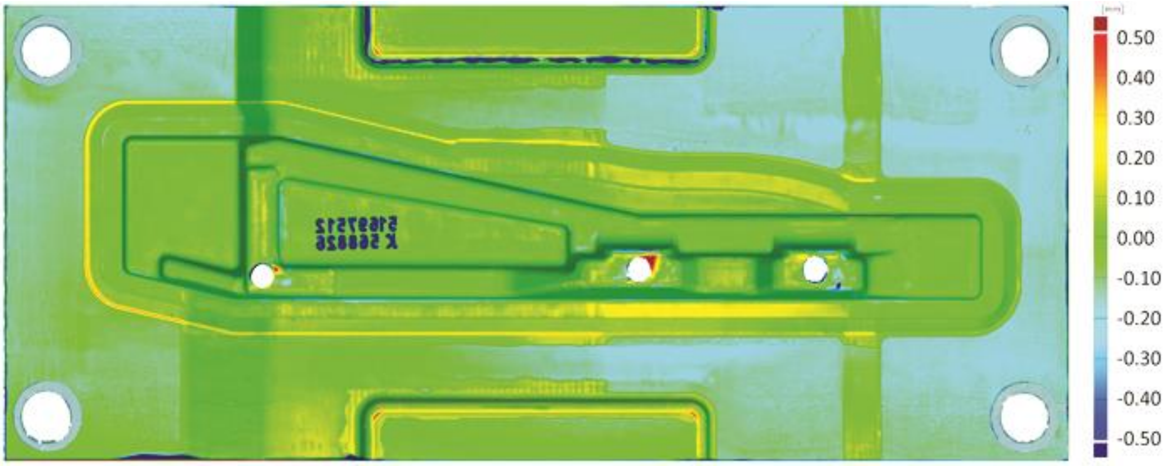


Fig. 5. The measured volume of the padding weld and machining allowance: a) the padding weld by comparing the scan of the die before and after the surfacing process; b) machining allowance by comparing the die's scans before and after machining; c) a suggested allowance with an average thickness of approx. 3 mm

The measurement by scanning presented in Figure 6a and the view in Figure 6b allowed to evaluate the effectiveness of the regeneration process, which ensured that the entire working part of the tool was filled with additional material. However, in the depth of the work pattern, inaccuracies are visible – errors caused during milling. There are also visible underfillings on the non-analyzed part, which was also surfaced – guide locks used for positioning the upper die in regard to the lower during forging. Scanning at this stage is an extremely useful tool because you can detect any surface defects and shape errors resulting from machining. Checking the quality of dies by scanning allows you to detect many geometric features using one template defined in the measurement environment (e.g. PolyWorks or GOM Inspect). These can be measurements of flatness, parallelism, perpendicularity, distance from the measuring base, etc.



(a)

(b)

Fig. 6. The die machined after the surfacing process: a) a scan of the die's surface compared to the CAD model; b) View of the die's surface after machining

Discussion

A comprehensive analysis of the effectiveness and efficiency of the regenerative surfacing process of forging dies was carried out. The research uses the capabilities of a measuring arm with a laser scanner. Scanning was used to measure defects on the used die, develop mechanical machining before surfacing, calculate the volume of the padding weld and machining allowance, as well as to assess the efficiency of surfacing and dimensional and shape compatibility after regeneration. The results obtained indicate the use of excessive allowances during surfacing, which could be reduced by up to 45% in regard to the entire volume of the padding weld. The possibility of using cavity measurement as input for developing machining programs before surfacing was also underlined. Similarly, the data obtained during the scanning of padding welds can be used in the selection of die machining programs after surfacing to avoid the risk of excessive loading of cutting tools during the turning or milling of padding welds.

Conclusions

The use of regenerative surfacing allows an effective reconstruction of worn parts of the working patterns of forging tools. The analysis of the regeneration process carried out on the interpretation of a selected forging die allowed to draw the following conclusions:

- it is recommended to develop a more efficient surfacing that does not generate such huge allowances, because it is a waste of material and requires a long time of machining;
- it is recommended to replace the manual surfacing with robotic, because it will allow to obtain a repeatable padding weld's shape, which will facilitate mechanical machining;
- supporting the process of forging dies regeneration through the use of laser or optical scanners can contribute to increasing the efficiency and effectiveness of these processes.

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