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PRODUCT QUALITY ASSESSMENT – MEASUREMENT AND ANALYSIS OF SURFACE TOPOGRAPHY

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Abstract

This paper concerns the issues of measurement techniques, analysis and assessment of the machined surface geometric structure. The aim of this work was to show the application of surface analysis in diagnosing the causes of discrepancies occurring in the manufacturing process, which may result from ill-matched (poorly fitting) process parameters. An appropriate system of control and interpretation of results may allow early reaction to unfavorable trends (for example blunting of the tool) and prevention of undesirable defects.
The subject of research was a waste basket used in the construction of retaining sewer systems. In this paper, the quality of the waste basket as well as its manufacturing process were analyzed and assessed. The research was carried out with the use of three measurement stands, i.e. optical microscopy (OM), scanning electron microscopy (SEM) and white light interferometer (WLI).
The surface analysis proved to be important from the viewpoint of outlining the production process as well as improving the product quality. The software used for topographical analysis appeared to be significant for the success of the analysis, providing notable economic effects, namely the lack of defects.

Keywords: surface metrology, topography, measurement devices, analysis of defects, quality.

1. Introduction

Measurement and identification systems concerning surface irregularities, which are used in modern production engineering, enable not only its supervision, but also the assessment of applied technologies.

The outer part of the top layer formed in the production process influences the usage properties and the quality of the produced components [1-5]. It is in direct contact with the environment and accumulates its impacts. It is crucial for the product quality to ensure the compliance of Surface Geometric Structure (SGS) with the Geometrical Product Specification (GPS) [6], which is to determine the departure of roundness, waviness, roughness, defects (scratches, cracks, pores, etc.). The roughness and defects often contribute to negative assessment of product quality [7, 8].

Typical technological processing of elements made of tool steel was the subject of the metrological analysis described in this paper. The research and correction of the product surface, which provides a good illustration of the issue discussed, was conducted with the view of mass manufacturing of a component used for the sanitary sewer system. This element is produced with the use of unconventional treatment, that is, among other things, with laser cuttings.

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2. Production automation and the point of conducted research and analysis of SGS

The aim of the production engineering is to optimize production as far as costs and shortcomings are concerned. Therefore, effective production depends on constant analyzing, diagnosing and improving. This, in turn, results in increased quality and customer satisfaction, and subsequently in the company's success.

The production process is closely connected with metrological evaluation [6, 9]. A key role is played by analysis of surface topography (or geometrical surface structure) [2, 4, 10-14]. This allows to supervise each stage of technological production (associated with machining of materials, such as cutting, turning, milling, etc.) and take immediate action in case of irregularities. What is more, it enables to change the parameters of production if necessary.

Any observed irregularities can be caused by mismatched (poorly fitting) process parameters. The appropriate system of control and interpretation of results may allow early reaction to unfavorable trends (for example blunting of the tool) and prevention of defects.

For financial reasons, it happens that a process is implemented without the application of proper control systems. Savings, however, are only ostensible. It is well known that the costs of removing incompatibilities are the smallest at the stage of planning, preparing, and implementing the process; when it comes to a finished product, removing its defects turns out to be most expensive, not to mention the loss of potential customers.

Taking and verifying measurements at every stage of the manufacturing process significantly increases its effectiveness and customers' satisfaction.

3. Material and methods of research

The subject of the present analysis is a waste basket (a strainer – Figure 1) which is applied to sewage (drainage) systems with the view of filtering solids from industrial wastewater.

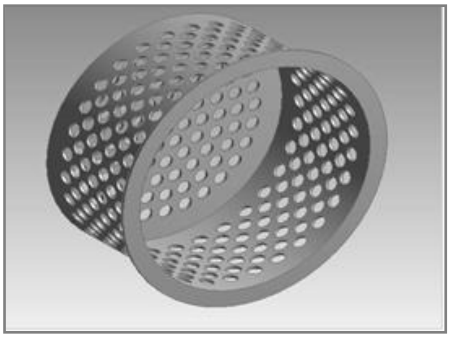

Fig. 1. The studied element – a waste basket.

The filtered pollutants can considerably influence the surface of the strainer. Taking into consideration the materials used in the production of this component, it is the pollutants made of glass that most heavily expose it to damage, scratching the component and causing it to break or crumble; whereas pollutants made of other elements, e.g. steel, ceramic, or cast iron, affect it to a lesser degree.

3.1. Characteristics of the material

Due to the fact that the waste basket is in constant contact with a volatile water environment, austenitic steel (AISI304) is used to its production. This type of steel contains

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a low level of carbon 18-8 chromium-nickel [15]. What is more, this material has high corrosion resistance and is easy to weld. Type 304 stainless steel is the material most often used in the chemical, paper, and food processing industries, as well as being applied to medical apparatus, and heat exchangers. In practice, the companies functioning in the above-mentioned areas most often order components made of this type of material.

Typical properties displayed by the above-mentioned steel type are the following: high corrosion resistance, susceptibility to polishing or treatment, rolling and printing.

The corrosion resistant steel varies as far as mechanical properties (Table 1) are concerned.

Table 1. Mechanical properties of the material.

AISI	Stability while drawing Rm [N/mm^2]	Slide border Rp [N/mm^2]	Toughness min %	Hardness max HRB
304	540÷880	195	45	88

The basic type of steel, i.e. austenitic one, has the highest resistance to corrosion after heat treatment, however at the expense of mechanical properties [15]. In order to improve the mechanical properties, the stabilizing elements (Ti, Nb) or elements strengthening the solution of austenite (nitrogen N) are added. Some properties of austenitic steel are better, but at the expense of others. For example, steel has a low level of ductility, showing not very high endurance to stretching. These drawbacks, however, are compensated by its quite good toughness and shock strength at room and lower temperatures.

Among other distinguishing technological properties displayed by austenitic steel, the following ones are worth mentioning:

- deformation due to cold, especially in case of deep drawing,
- significant difficulties in case of snipping, due to its susceptibility to hardening by a stroke,
- the possibility of emergence of corrosive fractures during mechanical polishing.

What is more, in an environment where chlorides appear, steel is characterized by the following properties:

- problems with heating and cooling due to thermal expansion,
- low thermal conductivity,
- lack of magnetic properties,
- the need for using a special type of smelting technologies and forming operations (cold and thermal).

3.2. Technological process

Due to the specificity of the production process (largely based on CNC machines) and material used for making waste baskets, it is important to choose correct treatment parameters [9]. Treatment is meant to make the technological process stable and consists of the stages presented in Figure 2.

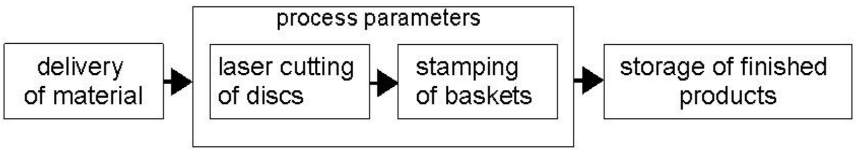

Fig. 2. The technological process of the basket production steps.

In the beginning stage of the production process, bores are made with the use of a laser cutter (the two-way one) – Figure 3.

Fig. 3. Cutting bores with a laser cutter

Next, flat discs are cut and passed to machining stands. Here, semi-products are processed with the use of drawing processes, which aim at achieving a correct construction of the component. The last stage of the process is to deliver the fully formed products to the storage point. Yet, cutting bores with a laser cutter is said to be the most important part of the whole technological process. Defects emerging on the surface geometric structure are linked to this very stage.

The analysis of the technological process and the results achieved in the course of research on the surface geometric structure presented the evidence that the way of cutting bores and the unconventional treatment method chosen for the research resulted in size discrepancies and low quality of the manufactured products. All of the identified surface damages may have a negative impact on the properties of the waste basket. Consequently, the basket may become blocked, which, in turn, may generate extra costs necessary to cover its maintenance and cleaning.

A serious consequence of clogging the baskets can be blockage of the drainage system, which can in turn lead to the flooding of buildings, such as production halls, putting companies at risk of making considerable money losses. Therefore, it is very important to analyze the production process, even though a product and the technological process themselves do not seem much complicated.

Costly attempts made to correct the movement of the laser cutter head failed to bring any improvement with regard to the manufacturing quality. It turned out that damages emerging on the surfaces of waste baskets and all discrepancies did originate from the power of the beam incorrectly adapted. It was noticed that once the power of the beam had been changed during the process of cutting bores, growths started to appear on the edges of the bores cut in the waste basket.

3.3. Measuring devices

While supervising the manufacturing process, the criteria of assessment of the product quality were carefully thought out [16]. The quality of the products (waste baskets), which originated from the technological process, was assessed on the basis of measurement and analysis of the surface topography.

The surface geometric structure of the studied elements was subject to research conducted with the use of three measurement methods:

- Optical Microscopy (OM),
- Scanning Electron Microscopy (SEM),

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– White Light Interferometer (WLI).

The optical microscopy (OM) with digital video recording allows to capture images of sample surfaces at different magnifications and directly record consecutive fields of view. Compared with other techniques, the advantage of the OM is that it allows observation of large areas of a surface. Its only drawback is that it fails to show the features of surfaces described by low roughness parameters (surfaces of high technological quality).

The scanning electron microscopy (SEM) allows, among others, a qualitative analysis of the surface irregularities. The advantage of SEM is very good resolution and quality of obtained images. The disadvantages are the necessity of using a vacuum and a small range in the *z*-axis.

The optical interferometer allows to capture the surface geometric structure with an ultra-high vertical resolution, up to 10pm (regardless of the applied magnification) [4]. Its operating principle is based on the use of one of the varieties of white light interferometry (WLI), so-called scanning broadband interferometry (SBI). The advantage of the WLI is a large measuring range in comparison with the OM and SEM, high accuracy of scanning and good resolution. Its major disadvantage, however, is a relatively small measurement area.

The use of different measurement devices (techniques) allowed to collect additional information on the characteristics of the surfaces formed in the manufacturing process (including irregularities) as well as enabling an analysis and interpretation of the results.

With the use of scanning electron microscopy and optical microscopy, surface images were registered in a non-contact manner (Institute for Sustainable Technologies - National Research Institute in Radom).

The measurement of the surface topography (damage) was performed on an optical interferometer (Institute for Sustainable Technologies - National Research Institute in Radom), using a non-contact scanning probe (with the lens enlarging images up to 10 times). The research results were evaluated with the use of sophisticated metrological software.

4. Results and discussion

The analysis of the surface topography was conducted within the areas located near the bores of the waste basket (the basket was presented in Figure 1).

The pattern and repetition of the size and type of damages was observed on the analyzed surfaces. The research results were subject to quantitative (measuring of damages) and qualitative analysis (visualizing of damages) with the use of three measuring stands and professional metrological software. The research which was conducted with the use of the non-contact measuring methods shows that the biggest discrepancy appears near the bores. The shape of the damages is irregular. The maximum size of the damage (irregularity, or so called growth) reaches 0,5µm. The common characteristic of all the irregularities is their accumulation near the bores. Yet, the further from the bore growths are distributed, the less deformed the shape is. At first glance, the damages looked like scratches, or cavities in the surface. Only after 3D visualization had been used, the real nature of the damages was revealed. Selected damages are depicted in the pictures below: Figure 4 (the results achieved with the use of optical microscopy OM), Figure 5 (the results achieved with the use of scanning electron microscopy SEM) and Figure 6 (the results achieved with the use of the white light interferometer WLI).

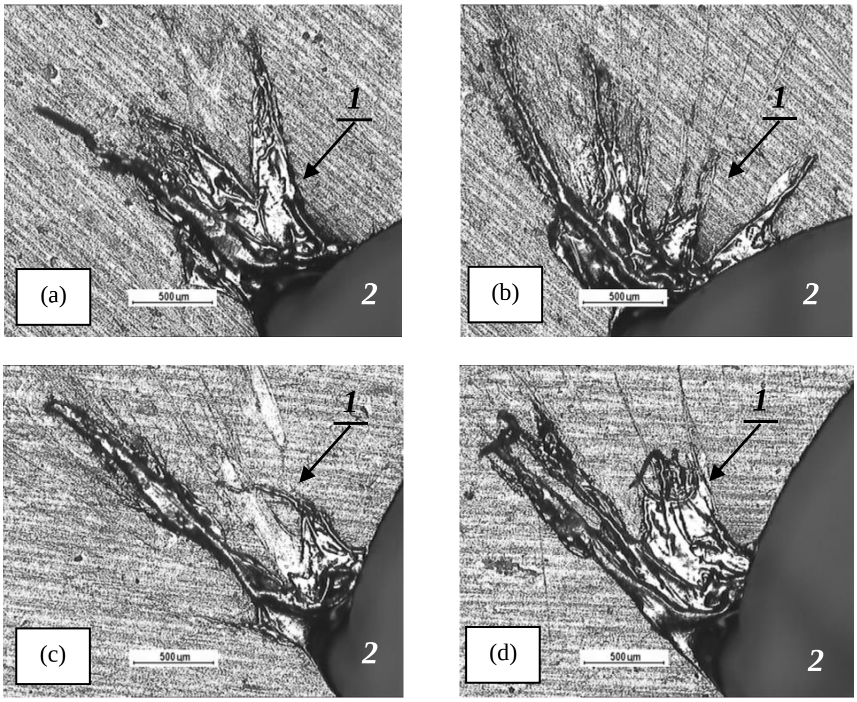

Fig. 4. The results achieved with the use of OM (total system magnifications x50)
1- damage (partially melted material), *2*- bore.

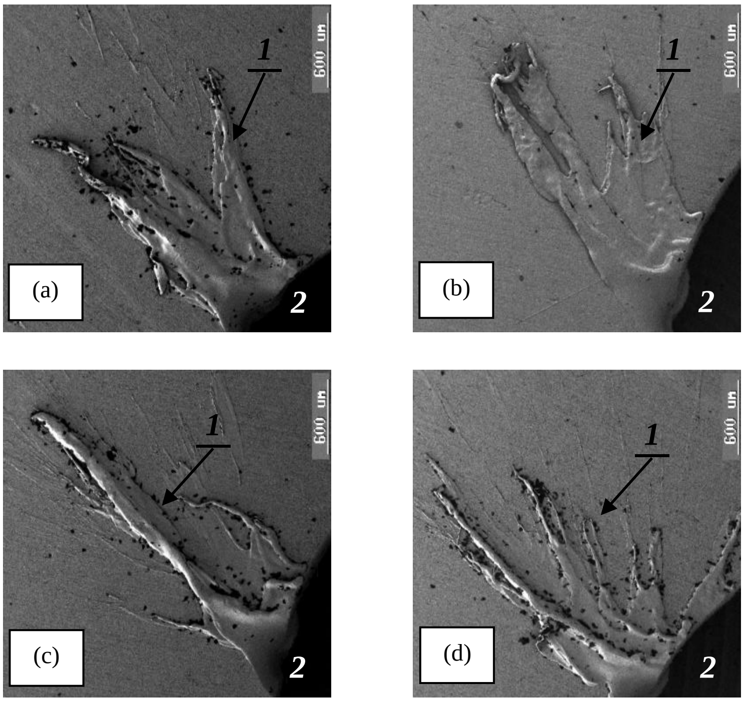

Fig. 5. The results achieved with the use of SEM (total system magnifications x40)
1- damage (partially melted material), *2*- bore.

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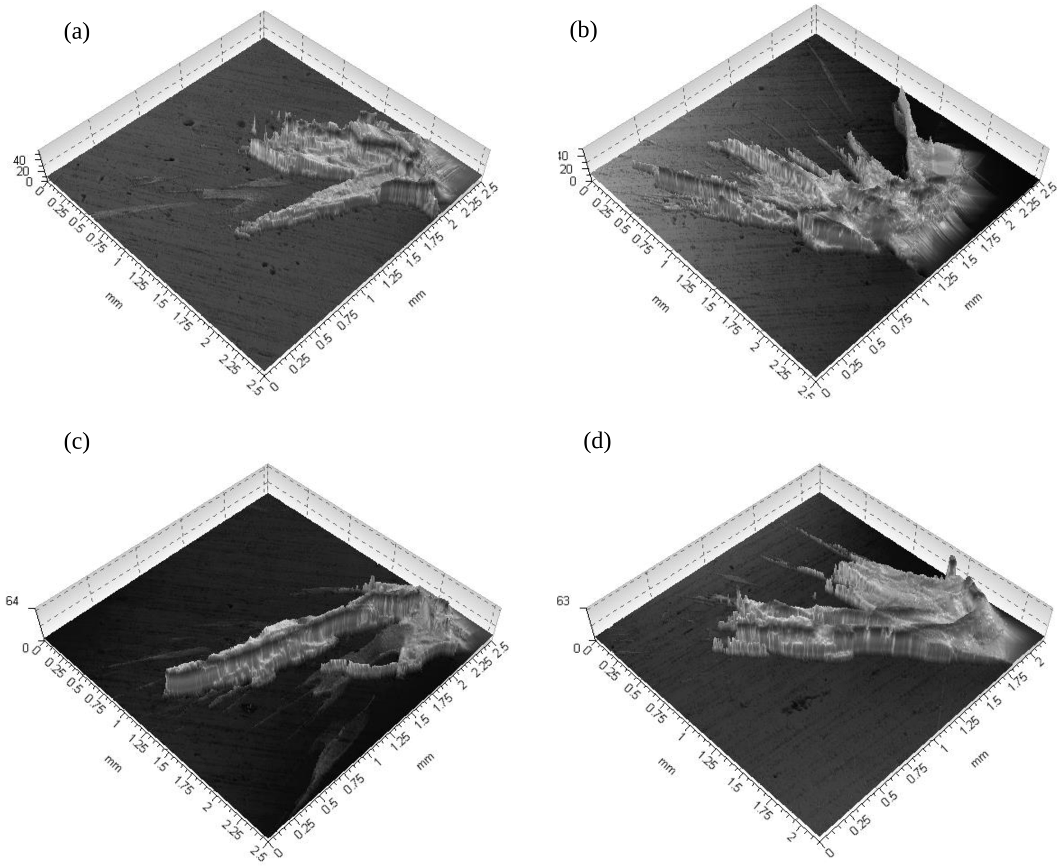
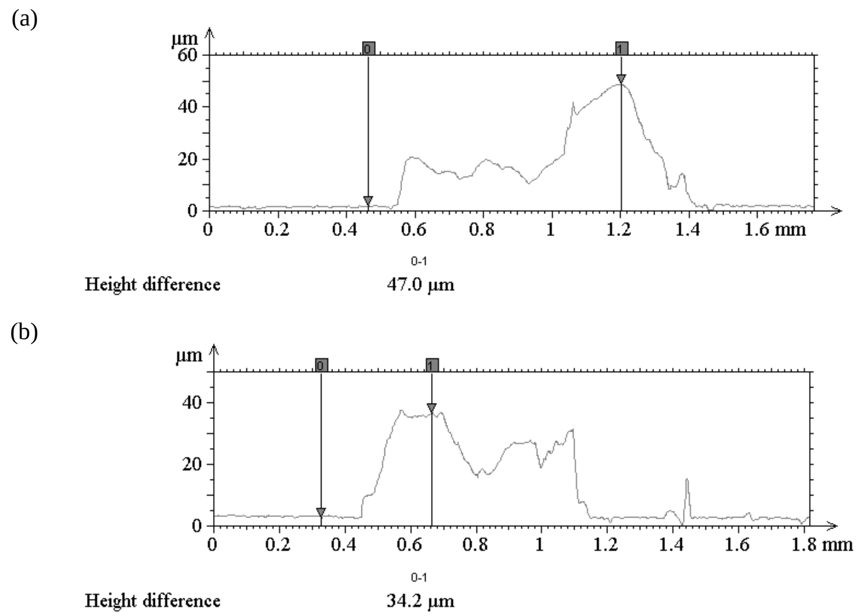
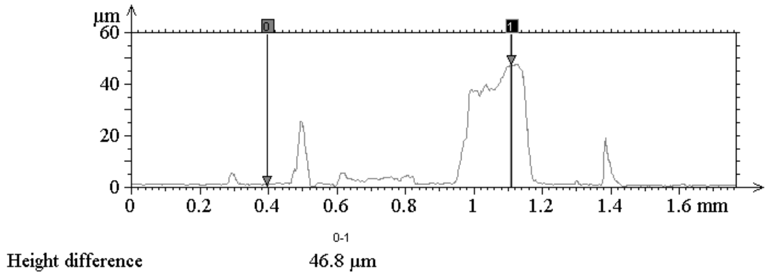


Fig. 6. The results achieved with the use of the WLI – damages (partially melted material).

The analysis shows that the existing discrepancies take about 30% of the examined surface around the bore. The damages have an irregular character. The section through the profile (Figure 7) very clearly shows the changes in amplitude.



(c)



(d)

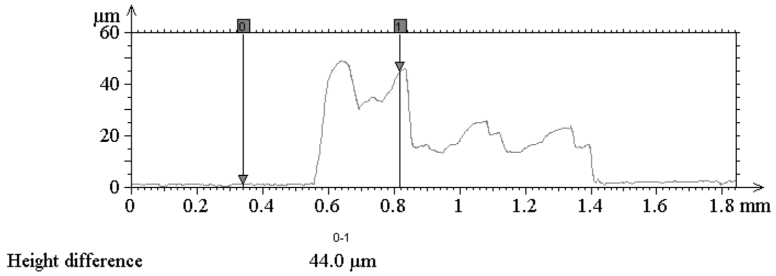


Fig. 7. The profiles of selected surface damages (partially melted material).

It is possible to eliminate the damages done and identified, if additional machining techniques are applied, for example sand blasting, thanks to which the undesirable irregularities could be removed. However the whole surface of the product would have to be flattened at the same time, which would increase the susceptibility to corrosion. On the other hand, application of other techniques would increase the cost of both the manufacturing process and final product. Another possibility is to reduce the laser cutting speed. However, doing that would decrease the efficiency of the process. Then, the problem might be solved if the power of the beam were stabilized. But, it seems that it would not change the efficiency of the process, while requiring beam guidance and trajectory corrections. Continuous monitoring of laser parameters would be necessary, with regard to the type and thickness of the cutting material. The process parameters can only be set experimentally through repeated topographical analysis with variable sample parameters. This gives satisfactory effects by reducing growth which is the main factor influencing the final shape, size, and product quality.

As far as the discussed issue is concerned, another solution would involve the modification of the manufacturing process of baskets. From the viewpoint of operation, laser cutting appears to be an expensive technology. Cutting thousands of small bores in short intervals will result in many quick and sudden movements of the laser head. The inertia forces arising in this way will certainly speed up the wear of power trains and guiding systems, lowering the precision of cutting. Given that the manufacturer has a *power* press, it would be reasonable to consider equipping it with punches for cutting bores and implementing the whole process with a single device.

Undoubtedly, the throughput of a basket could be improved by changing the construction of bores. Increasing the angle between the bottom and the side of a bore (Figure 8) would allow to reduce the influence of surface irregularities (defects) around these bores upon accumulated impurities clogging the bores. Confirmation of this fact, however, will require further research.

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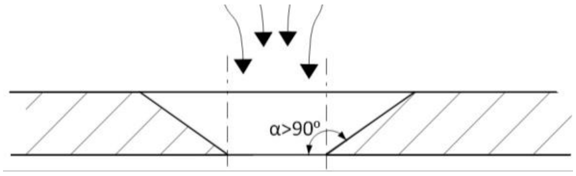

Fig. 8. Proposed shape of the waste basket bores.

It has to be noted, however, that all the suggestions presented above are associated with increased costs of the production process; hence, whichever of them is chosen, it has to be accompanied by an economic analysis.

Yet, it seems undeniable that if the support and control systems are effectively implemented, the technological process will be easily controlled, loss of stability will be immediately handled, and defects will be prevented from ever occurring - Figure 9 presents a scheme of the support and control systems.

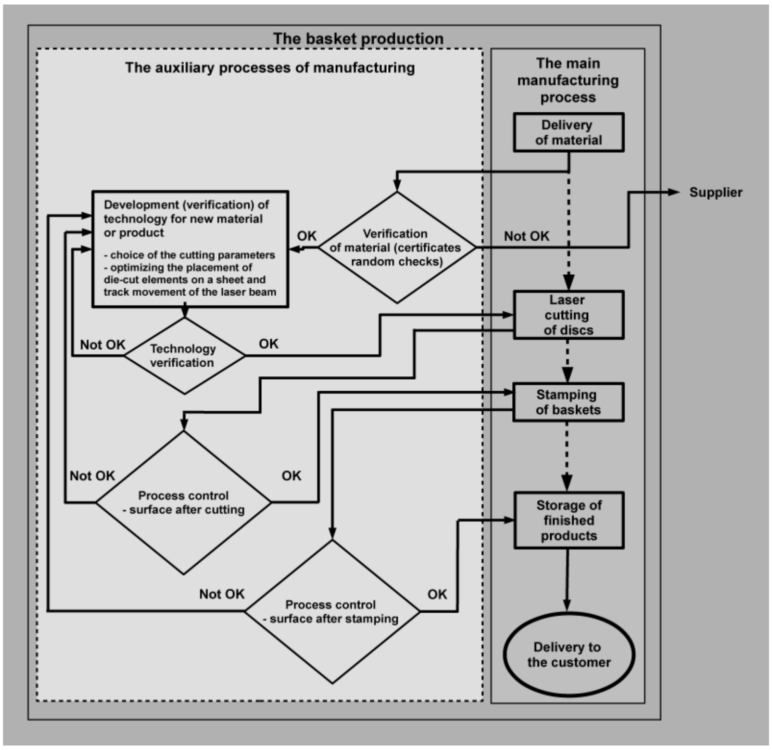

Fig. 9. Scheme of the support and control systems.

5. Conclusions

The surface geometric structure which is crucial for the quality of produced components depends on technological parameters adapted for the manufacturing process. Accurate setting of the surface functional parameters, i.e. the bores of a waste basket, enabled assessment of the product quality.

The program of the research turned out to be a key factor enabling identification of the conditions contributing to the surface damage. To cast more light on the issue, it was necessary to combine various measurement methods, owing to which the surface could be studied at different angles. A variety of images achieved from the use of various methods facilitated analysis and resulted in accurate conclusions.

What played an important role in improving the efficiency of unconventional treatment (laser treatment) was the analysis of surface topography, which helped to identify damages.

Other methods which had been previously employed were not as successful and generated false conclusions. As the analysis shows, defects resulted from the interpolation of several factors, especially in the course of unconventional treatment.

Furthermore, the surface analysis proved to be important from the viewpoint of outlining the production process as well as improving the product quality. The software used for topographical analysis appeared to be significant for the success of the analysis, providing notable economic effects, namely lack of defects.

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