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Influence of Allowance Value on Formation of Surface Roughness During Grinding with Flap Wheels After Shot Peen Forming

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Abstract **– In the aircraft industry to obtain the necessary form of long panels and sheaths the shot peen forming is successfully used. Due to impact of shot on the processed surface, the specific microgeometry is formed, the characteristic feature of this microgeometry are the numerous dimples of shot with different diameters and depths. At the same time, the depth of the dimples significantly exceeds the valleys of the surface microroughnesses formed as a result of the previous treatment. The presence of these dimples leads to an increase in surface roughness. Therefore, after shot peening the mandatory requirement is implementation of surface grinding with flap wheels for partial removal of the shot dimples. During grinding with flap wheels, depending on the value of allowance for grinding on the treated surface, a new microrelief is formed in the form of a combination of the traces of abrasive grains of flap wheels during grinding and the remains of the dimples from shot peen forming. Since the dimples have a spherical shape with a much larger radius of curvature than their depth, they have a specific effect on the degree of coverage of dimples, roughness and removal of material of treated surface. The paper presents an analytical description about the change process of the area covered with current dimples and roughness during grinding with flap wheels around the surface pre-treated with shot peening depending on the set value of allowance. Based on the results of the research, mathematical models were built to determine the current area of coverage with dimples, the average value of the depth and degree of coverage of the remaining dimples, the amount of material removed from the treated surface and roughness during grinding with flap wheels, and a numerical method for determining the allowance for obtaining the permissible degree of coverage and the required values of roughness.**

Keywords – shot peening; grinding with flap wheels; dimple; degree of coverage; surface roughness during shot peening; surface roughness during grinding with flap wheels; volume of material after shot peening; volume of material after grinding; allowance.

I. INTRODUCTION

To obtain complex curvilinear forms of the surfaces of panels and sheaths, as well as hardening operations, shot peening is widely used. Grinding with abrasive flap wheels are a mandatory part of the process of forming of long-length large-sized surfaces. It is carried out in order to improve the quality of the initial surface obtained after shot peen forming (fig. 1 a, b) [1-6].

From the impact of shot flow, a specific surface roughness profile is formed on the surface of the workpiece, which is characterized by numerous dimples of shots with different diameter and depth [7, 8]. At the same time, the distribution of dimples on the treated surface is chaotic (random) [9].

The results of our study of numerous samples treated with a shot in shot peen forming showed that a low degree of coverage (up to 40 %) at shot peen forming, the metal influx around the dimples is commensurate with the height of the microrelief of the surface treated with milling before shot peen processing, and there is practically no overlap with each other's dimples.

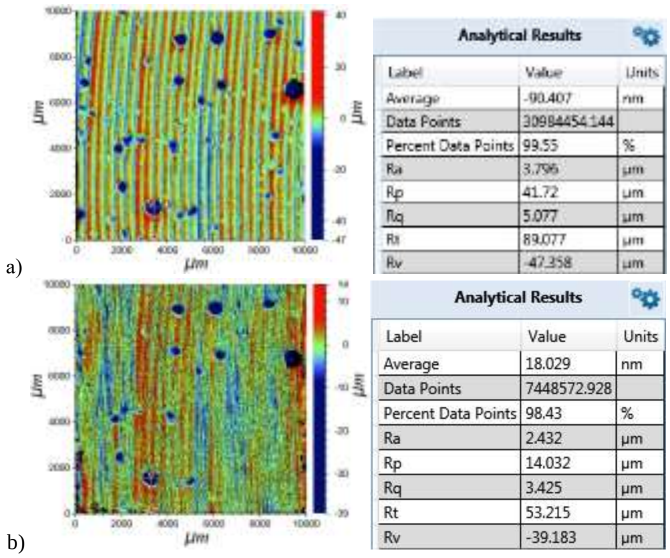

Fig. 1. Typical topography of the sample surface after shot peen forming and grinding with flap wheels: a – after shot peen forming; b – after grinding with flap wheels

During grinding, first of all, a layer of the surface microrelief from the previous operation (milling) and the influx formed as a result of shot peen processing is removed, and when the grinding process is continued, the subsequent layers of the surface are removed in areas not covered with the dimples.

The dimples in the form of voids has a shape close to spherical with radii of shot (1.5-3 mm) [10], much larger than the depth of dimples (tens of microns), so the volume of dimples has a significant impact on the volume of the metal removed. Therefore, the area covered with dimples on the treated surface and the volume of metal is not directly proportional to the cutting depth. Thus, by increasing the thickness of the removed layer of material during grinding, the area and the degree of surface coverage of the remaining dimples decreases and the number of grains of flap wheels simultaneously participating in the grinding process becomes greater. This leads to an increase in the volume of material to be removed, which in turn requires a constant increase in the forces and cutting power during grinding. Cutting forces and power are stabilized as we approach the complete removal of traces of dimples.

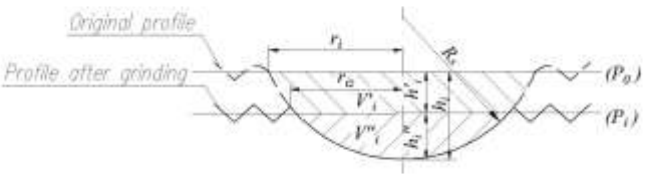

Fig. 2. Dimple – model of shot after shot peening and grinding with flap wheels

II. Character of removal of material and formation of surface roughness during grinding after shot peen forming

Fig. 2 showed the dimple - model formed on the surface pre-treated with milling during shot peening and subsequent grinding with flap wheels.

Figure 2 introduced the following symbols: Rs is radius of shot; h – thickness of the panel from the center plane P_0; h_i – depth of i-th dimple of shot from the original center plane P_0; h_i' – distance of the i-th dimple of shot from the original center plane P_0 to the center plane P_i; h_i'' – depth of i-th dimple of shot from the center plane P_i; r_i – radius of i-th dimple of shot in the center plane P_0; r_{igr} is the radius of the i-th dimple of shot in the center plane P_i; V_i' is the void volume of a truncated part of the i-th dimple of shot between the planes P_0 and P_i; V_i'' – the void volume of the i-th dimple of shot after grinding from P_i.

If F_b is denoted by a base area, in which, after shot peen treatment the degree of coverage by the dimples became stable. Under the base area (by definition) there is the area, the dimensions of which provide reliable values of the degree of coverage and surface roughness in the control of surface topography.

The degree of coverage of the dimples is an important indicator of the force impact of the shots and is determined as a percentage of the total area covered by the dimples in the sample flat surface and the total surface area of the study sample surface:

$$K = \frac{\sum_{i=1}^{n} \pi \cdot r_i^2}{F_b} \cdot 100\% \qquad (1)$$

Given that the shape of the dimples is close to spherical [10], then:

$$K = \frac{\pi \cdot \sum_{i=1}^{n} (2R_S \cdot h_i - h_i^2)}{F_b} \cdot 100\% \qquad (2)$$

In the process of grinding with flap wheels when removing a layer of material thickness a, the total area of coverage of the dimples is reduced that leads to a decrease in the degree of coverage K_a:

$$K_a = \frac{\pi \cdot \sum_{i=1}^{m} (2R_S (h_i - a) - (h_i - a)^2)}{F_b} \cdot 100\%, \qquad (3)$$

where a – allowance for grinding; n – number of dimples on the base area after the shot peen forming; m – number of dimples remained after grinding with the allowance a, $m < n$, $m \in n$.

To preserve a form of the part obtained during shot peen forming, after grinding, it is necessary to provide the necessary bending moments of the surface layer by preserving certain residual stresses formed during the shot peen processing, which are related to the number of remaining dimples and their depth. The number of dimples and their depth in turn determines the current degree of coverage of the remaining dimples. The depth of dimples for control in this case is proposed in the form of a mathematical expectation of the depth of the remaining dimples on the base surface area. Similar to the definition of the mathematical expectation of the radius of dimples in [10], the averaged depth h_a can be determined by the following formula:

$$h_a = \frac{\sum_{i=1}^{n} h_i^2}{n} \tag{4}$$

Taking into account that the influx around the dimples after shot peen forming does not exceed the height of microrelief of the surface treated by milling before shot peening, the volume of material of the treated panel after shot peening on the base area V_{peen} can be determined by the following formula:

$$V_{peen} = F_b \cdot H - \sum_{i=1}^{n} V_i \,, \tag{5}$$

where V_i – the volume of void of the i-th dimple.

After grinding with flap wheels, some of the dimples still remain, according to fig. 2 the volume of material after grinding on the base area V_{gr} can be determined as follows:

$$V_{gr} = F_b \cdot (H - a) - \sum_{i=1}^{m} V_i^{''} \tag{6}$$

Thus, the volume of material V_m removed by grinding can be determined by the following formula:

$$V_m = V_{peen} - V_{gr} \tag{7}$$

$$V_m = F_b \cdot a - \sum_{i=1}^{n} V_i + \sum_{i=1}^{m} V_i^{''} \tag{8}$$

Given that the form of the dimples is close to spherical [10], then:

$$V_m = F_b \cdot a - \sum_{i=1}^{n} \pi \cdot h_i^2 \left(R_S - \frac{1}{3} h_i \right) + \sum_{i=1}^{m} \pi \cdot (h_i^{''})^2 \cdot \left(R_S - \frac{1}{3} h_i^{''} \right) \tag{9}$$

However, h_i'' for the number m of dimples is also associated with allowance a and can be determined by the thickness of the material layer to be removed (allowance) and the depth of the dimples after shot peen forming.

$$h_i^{''} = h_i - a \tag{10}$$

Thus, the volume of the removed material can be expressed by the following dependence:

$$V_m = F_b \cdot a - \pi \cdot \sum_{i=1}^{n} h_i^2 \left(R_S - \frac{1}{3} h_i \right) + \pi \cdot \sum_{i=1}^{m} (h_i - a)^2 \cdot \left(R_S - \frac{1}{3} (h_i - a) \right) \tag{11}$$

From the dependence (11) it follows that the task of determining the volume of the removed material during grinding is simplified, since it is not necessary to measure the depth of the dimples left after grinding, but the data on the initial depth of the dimples after shot peen forming are used.

It is not difficult to notice that $\sum_{i=1}^{n} \pi \cdot h_i^2 \left(R_S - \frac{1}{3} h_i \right)$ is the total volume of voids of dimples after shot peen forming and constant on the base area for the surface treated by shots. This total volume is not difficult to determine using a scanned surface on a three – dimensional profilometer.

At a known value of the thickness of the removed material, according to [11] the arithmetic mean deviation of the profile within the base area in accordance with the thickness of the removed material – the allowance for grinding Sa_{gr} can be determined by the following expression:

$$Sa_{gr} = 0.5 Sa_{gr} + \frac{2\pi}{F_b} \cdot \sum_{i=1}^{m} (h_i - a - h_k^{''})^2 \cdot \left(R_S - \frac{1}{3} (h_i - a - h_k^{''}) \right), \tag{12}$$

where Sa_{gr} – the arithmetic mean deviation of the profile within the base area of the surface treated by grinding without taking into account the shot dimples; h_k'' – the distance from the center plane of roughness without taking into account the shot dimples to the final center plane of the surface roughness after grinding with taking into account the remaining dimples, this distance is determined by the follow expression [11]:

$$h_k^{''} = \frac{\pi}{F_b} \cdot \sum_{i=1}^{m} (h_i - a)^2 \cdot \left(R_S - \frac{1}{3} (h_i - a) \right) \tag{13}$$

In this case, equation (12) is valid only if there is a sufficient total volume of voids of the remaining dimples after grinding, which provides a displacement of the center plane downwards, that is:

$$\frac{2\pi}{F_b} \cdot \sum_{i=1}^{m} (h_i - a - h_k^{''})^2 \cdot \left(R_S - \frac{1}{3} (h_i - a - h_k^{''}) \right) >> 0.5 Sa_{gr} \tag{14}$$

The results of experimental studies of numerous authors of the roughness of the surface treated by grinding with flap wheels after milling (without shot peen processing) showed that after removal of the complete roughness of the milled surface, regardless of the time of further grinding (with preservation of the processing mode), an achievable roughness with a practically constant value is formed on the treated surface. Therefore, in formula (12), the arithmetic mean deviation of the profile within the base area varies depending only on the total volume of voids of the remaining dimples, which in turn depends on the thickness of the layer being removed (allowance).

Thus, on the basis of the dimples of the scanned surface treated with shot peening and equations (9) and (10), depending on the values of a specified allowance (in the range from Rz_{mil} – the average height of the roughness of the milled surface before treatment with shot peening to the value of the difference $Rq_{peen} - Rz_{gr}$, where Rq_{peen} – the maximum depth of the dimples on the control area; Rz_{gr} – the average height of the roughness of the surface processed by grinding, excluding shot dimples) numerically we find the remaining dimples and their size. Further, according to formulas (2) and (3), we determine the area and degree of coverage with dimples, according to formula (4) and numerically determine the number of remaining dimples and the average value of the depth of dimples, according to formula (9) – the total volume of voids of dimples and the total volume of the material to be removed, and according to formulas (12) and (13) – the corresponding displacement of the center plane and the arithmetic mean deviation of the profile, respectively.

Fig. 3, 4, 5 and 6 show graphic dependences (with an approximation error of not more than 2%.) the results of calculations of the degree of coverage of dimples, the number of remaining dimples and the average depth of dimples, the total volume of voids dimples and the volume of the material to be removed, as well as the actual dependence of the displacement of the center plane and the arithmetic mean deviation of the profile, depending on the value of a given allowance.

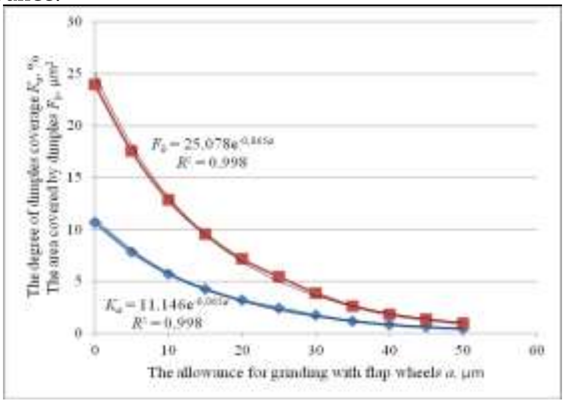

Fig. 3. The actual dependence of the total area and the degree of coverage of dimples on the allowance for grinding

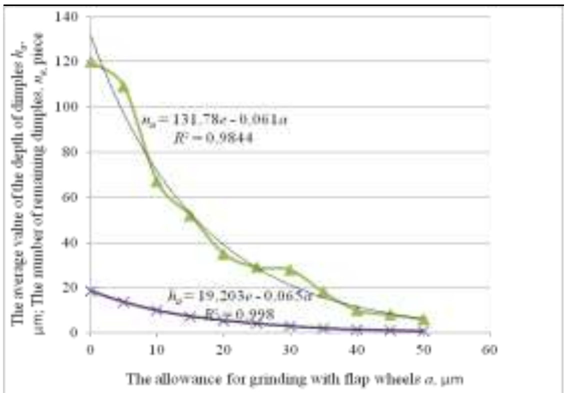

Fig. 4. The number and average value of the depth of dimples, depending on the allowance for grinding

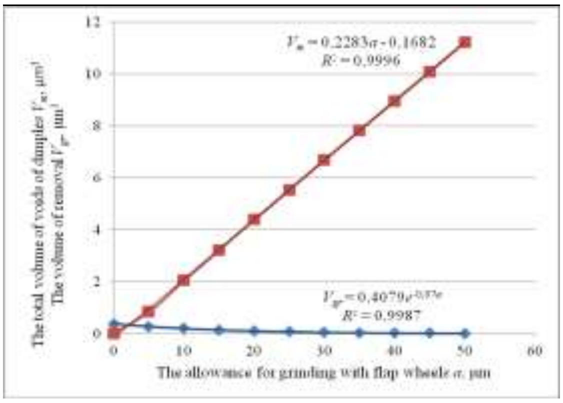

Fig. 5. The actual dependence of the total volume of voids dimples and volume of removal of material on the allowance for grinding

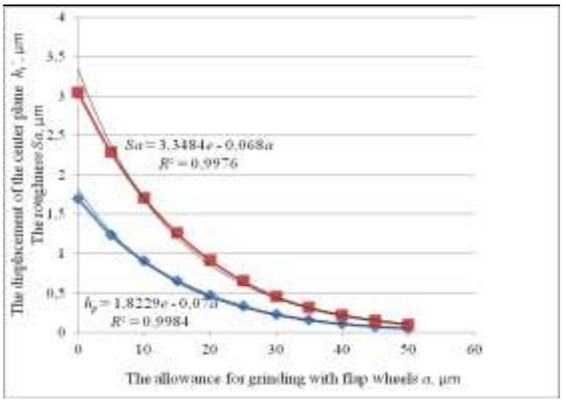

Fig. 6. The actual dependence of the displacement of the center plane and the arithmetic mean deviation of the profile on the allowance for grinding

The calculation was carried out for the base area of 15×15 mm [10] of the sample of aluminum alloy B95. According to the technology of fabrication of large curved aircraft panels and sheaths, the sample was first milled to a surface finish *Ra*0.4, after processed by shot peening with steel shot with a diameter of 3.5 mm on the Equipment for shot peening of contact type UDF-4M with follow processing mode: frequency of rotation of the shot peen wheel 1200 rpm, longitudinal feed 2.5 m/min. After shot peening, the treated surface of the sample is scanned on a three-dimensional optical profilometer to obtain the necessary data about the dimples (in this case, a total of 120 dimples with a depth from 3.2 to 90.5 microns, the total degree of coverage by dimples 10.66%).

The value of roughness in Fig. 6 obtained taking into account only the dimples and the nominal surface for a specific value of the allowance. To obtain the final value of the roughness on the surface to be treated, when grinding after shot peen forming, it is necessary to take into account the roughness of the part of the surface without dimples cleaned with flap wheels (formula 12).

With the help of graphs in fig. 3-5 it is not difficult to determine the necessary allowance to ensure the required value of the degree of coverage of dimples, the volume of material removal and the arithmetic mean deviation of the profile within the base area.

III. SUMMARY

- The dimples formed as a result of shot peen forming, as well as the degree of dimples coverage play a crucial role in formation of roughness and removal of material from the treated surface in implementation of the technology of shot peen forming with subsequent grinding with flap wheels.
- A method for determining the allowance for grinding with flap wheels after shot peen forming, which allows to calculate the degree of coverage, the number and average value of the depth of the remaining dimples, the volume of the material and the required surface roughness is proposed.

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