Experimental Verification of Deburring by Magnetic Abrasive Finishing Method

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ABSTRACT

The conditions and results of research of deburring as applied to large areas using MAF method and designed face magnetic inductor are described in this paper. Steel and aluminum samples were finished. Burr are formed in drilling.

The problems connected with burr removal after drilling are stated. The result of experiment allows to consider MAF process as perspective for burr removal in surfaces with numerous holes, grooves and other elements with burrs.

1 INTRODUCTION

From the beginning magnetic-abrasive finishing was used only for surface finishing. However its first industrial applications have shown that edges are rounded simultaneously with surface polishing owing to cutting properties of loose abrasive, which has also magnetic properties [1].

If a workpiece is made from ferromagnetic material, its edges in magnetic field becomes magnetic flux concentrators. And they are finished more intensively than other surfaces. This resulted in development of new technological application of MAF method for hardening of metal cutting tools by preliminary rounding of their cutting edges [2,3].

First this method was used for deburring on stamped blanks made from stainless steel [3]. The problem was that during sheet blanking stamp edges became blunt quickly which caused large burr (up to 3-4 mm) formation along the workpiece contour. Burrs had high strength and were hardly removed manually. Application of MAF scheme (fig.1) allowed to remove burrs efficiently. Workpiece has transnational motion (v_f) along the working zone between poles of electromagnet and at the same time it oscillates in vertical direction (n_{osc}).

At present time, small burrs are successfully removed on small workpieces together with polishing using the device developed by Prof. Takeo Shinmura in Japan (fig.2). Workpieces together with steel pins are put inside container 1. The disk 2 is rotated under the container bottom with fixed on it permanent magnets. Thereby steel pins and workpieces are forced to move inside container.

Interesting researches are done in the area of deburring using MAF by Hungarian professor Janos Kodacsy.

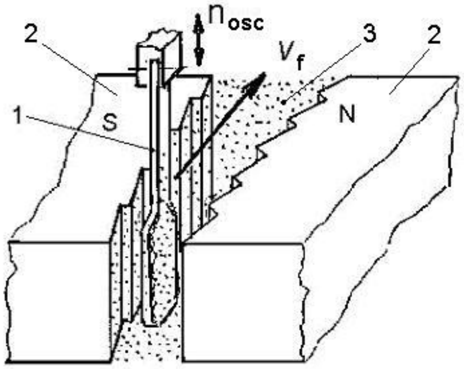


Fig.1. Removal of burrs located along the profile of workpiece made from sheet material.

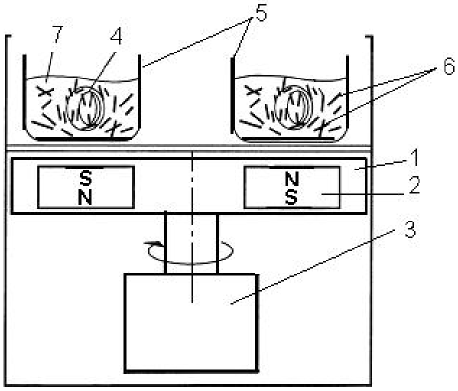


Fig.2 Removal of small burrs using MAF by T.Shinmura's method

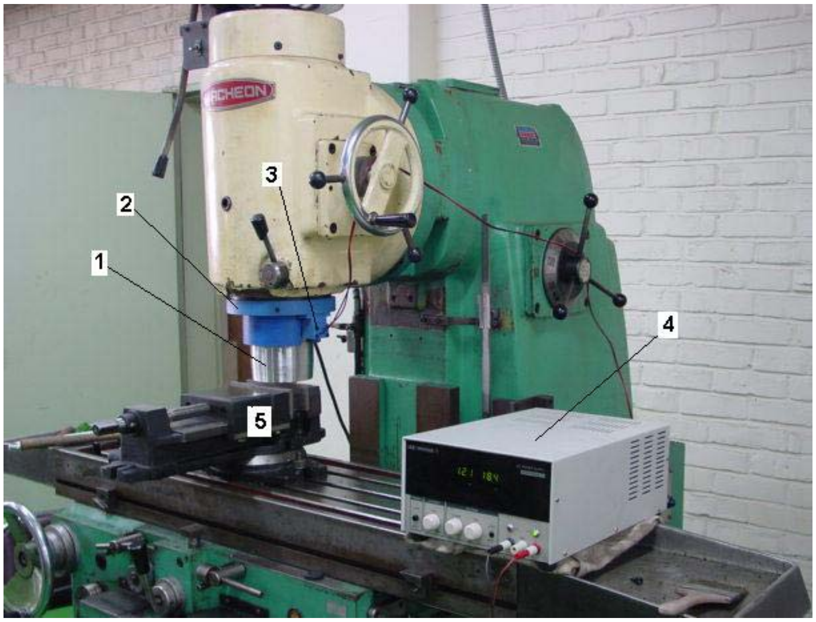
2 PROBLEMS OF DEBURRING AFTER DRILLING

Drilling process is most popular in machining. Therefore the burr problem is generally very serious. Burrs are formed when drill enters and exits hole. Mostly burrs formed in exit stage are much larger and cause serious problem in deburring. When the exit burr in drilling is formed inside cavity or inside hole in crossing holes, the tools for deburring is not accessible. In this case very special tools must be used to deburr, which increases the deburring cost. And sometimes deburring becomes impossible.

Burrs are inevitably formed in every machining process as a result of plastic deformations. The effect of burrs on products becomes more serious because it causes some critical problems like deterioration of surface quality. It reduces product life and precision. The effort to solve the burr problem can be approached from two aspects. One is by minimization of burr formation to reduce the cost for deburring and keep the precision of parts. This approach is direct and desirable in most machining process. To minimize burr formation, the mechanism of burr formation must be analyzed. However the effort for minimization is sometimes very much limited in satisfying the requirement of product. Therefore deburring process is mostly necessary. However the deburring cost is determined by the size of burr and location. Usually the cost increases as the size becomes larger. Magnetic abrasive deburring method can be specially used to solve the problem in deburring the burr inside hole which is difficult to be deburr by usual deburring method due to its flexibility of the powder brushes. Also this flexible property can be used to deburr the micro burrs formed in miniature parts. The usual mechanical deburring method will induce the deformation of parts due to the deburring force. The deburring forces in magnetic abrasive deburring which is represented by magnetic intensity can be controlled by current easily. Therefore the application of magnetic abrasive deburring method will be successful for micro burrs.

3 DESIGNING OF MAGNETIC INDUCTOR

Research work for revealing capabilities of MAF method for burr removal after drilling are done in Konkuk University, Precision Machining Laboratory in 2002. To this end the device developed. Its general view is shown in figure 3. The device consists of face magnetic inductor 1, casing 2, closing collector rings, sliding conductor contact 3 and dc source 4. Inductor 1 is fixed in machine spindle and can be set in rotation. Workpiece can be fixed in usual machine vice 5 or in the additional device.



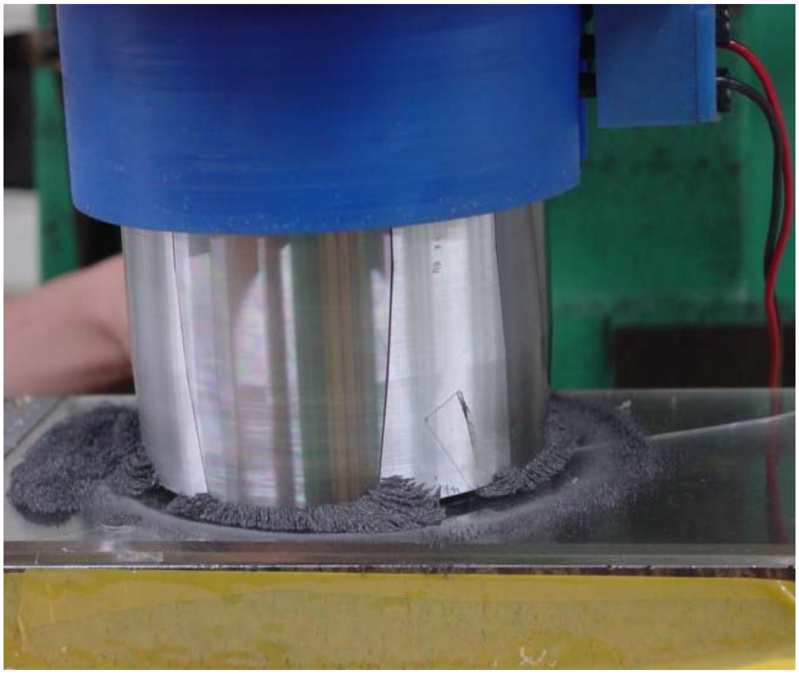


Fig.4 Working zone of magnetic inductor

Calculation of magnetic inductor was done by graphico-analytic method using theory of magnetic circuits. Requirements specification for calculation are:

- External diameter of external inductor pole – 110 mm;
- Inductor height – 60 mm;
- Height of working gap – 2 mm;
- Workpiece are made from ferromagnetic material;
- Magnetic induction in the external working gap filled up with ferromagnetic powder – 0.8 T;
- Magnetic induction in the internal working gap filled up with ferromagnetic powder – 1.2T.

Consequently it was obtained that:

- Magnetizing coil must have magnetomotive force not less than 2300 ampere turns;
- Calculated value of magnetic induction in the external working gap filled up with magnetic-abrasive powder is 0.8 T at working gap height of 2 mm;
- Calculated value of magnetic induction in the internal working gap filled up with powder is 1.1 T.

For magnetizing coil with copper wire which has diameter 0.8 mm:

- Permissible current for continuous work is – 1.2 A;
- Number of windings – 1920;
- Ohmic resistance of coil – 11.2 O;
- Maximal required current source voltage is – 14 V.

Magnetic inductor was produced by Korean company Technorise. Measurement of magnetic induction in the working gap of the magnetic inductor are made using Hall-device.

However, it must be noted that magnetic induction have been measured only in external working gap. The gap was filled up with air (without magnetic-abrasive powder).

To measure magnetic induction and set other experiments steel ferromagnetic plate 1 was manufactured. Samples 3 and plates 5, 6 made from ferromagnetic and non-magnetic materials can be fixes on it by screws (fig. 5).

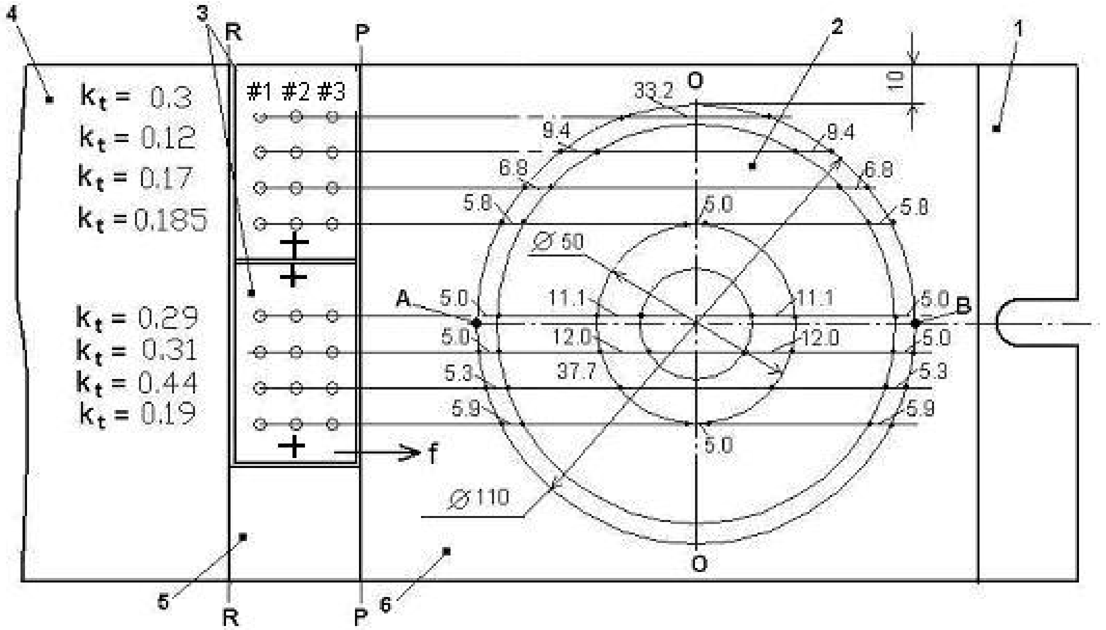


Fig.5. Arrangement of magnetic inductor 2 and samples 3 during inductor tests and MAF experiment.

Measurement of magnetic induction in external working gap at current I = 1.2 A showed that:

- magnetic induction was 0.35 T above the non-magnetic plate 6 (thickness 5 mm);
- magnetic induction was 0.98 T above the magnetic plate 1.

3 EXPERIMENTAL WORK

3.1.Preparation of samples

For this experiment aluminum and steel samples were prepared. 3 rows of holes with ∅ 3 mm were drilled in them. Burrs in each hole were measured before and after MAF in 4 points using digital measuring gage.

Each vertical row of holes had different drilling conditions (table 1). During MAF horizontal rows of holes are in different finishing conditions since duration of their contact with magnetic-abrasive powder is different and the trajectory direction of grain confined in poles of rotating inductor is different (see fig.5). Duration of contact of each horizontal row of holes with powder is proportional to total length of pole chords passing above each horizontal row of holes during line feed *f* of machine table with samples under the rotating inductor. Chord lengths are shown in figure 5. Duration of actual time of contact τ_i of horizontal row of holes with powder during one table strike can be estimated by formula:

$$\tau_i = k_t \cdot T\ , \qquad (1)$$

where T – duration of inductor passing above the sample; k_t – coefficient of actual time of contact with powder.

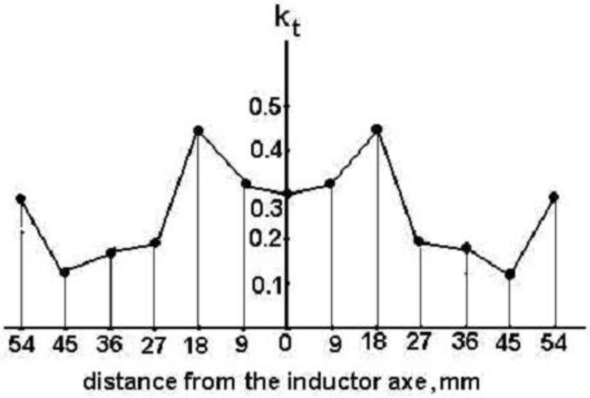


Fig.6. Diagram, characterizing non-uniformity of duration of contact of powder with sample parts located differently relative to inductor axis.

All said above means that allowance will be removed non-uniformly. Correspondingly, burrs will be also removed non-uniformly.

Experiment with aluminum samples proved this fact.

3.2 Deburring of aluminum samples

Experiment conditions:

Material of samples	Al6061	Coil current	1,2 A
Material of powder	Fe (35%) +NbC (65%)	Height of the working gap	2 mm
Graininess of powder	100/150 mkm	Rotation frequency of spindle	130rpm
Volume of powder portion	13 cm^3	Table feed	f_m= 342 mm/min

3.2.1 Influence of duration of finishing and sample arrangement relative to inductor on deburring result

The number of table strokes was changed from 0.5 to 2. Duration of 1 stroke is T=0.41 min. Actual duration of contact of finished parts was: τ_I = 1.8 ...6.6 sec at T=0.2 min-; τ_I = 2.9...10.9 sec at T=0.4 min -; τ_I = 5.9...21.7sec at T=0.8 min.

Initial burr height varied in the range 0.080...0.380 mm.

After MAF burr height was 0.021...0.132 mm.

The results are as follows: Increase of duration of MAF is accompanied by burr height decrease with average speed 0.5%h_{b1}/sec. Because of small magnetic induction (0.37T) in the external working gap powder is actively thrown out by centrifugal forces. After the completion of 2nd strike the number of powder decreased on 25 % from initial volume. Burrs located under internal pole with ∅50 mm are most intensively removed. In this place the value of magnetic induction is high and centrifugal forces dispersing powder are low. Burr height decrease in this part of finished surface was 70...80% during the first 0.5 table strokes. The following strokes of table didn't change burr height. This testifies to low volume of powder left in the working gap after the first 0.5 strokes of table..

Non-uniformity of allowance (and burr) removal in different parts of samples was confirmed by measurement of sample height in the same points before and after MAF (fig.7)

Non-uniformity of allowance removal in the finished surface after 1 table stroke was 33.2±10.2 mkm (±30.7%). Removed allowance in the area with width of 50 mm, symmetrical relative to inductor axis is larger and has less non-uniformity 41.6±1.4 (±3.4%). This implies that non-magnetic workpieces and samples must be located only in the 50 mm area, symmetrical to magnetic inductor axis.

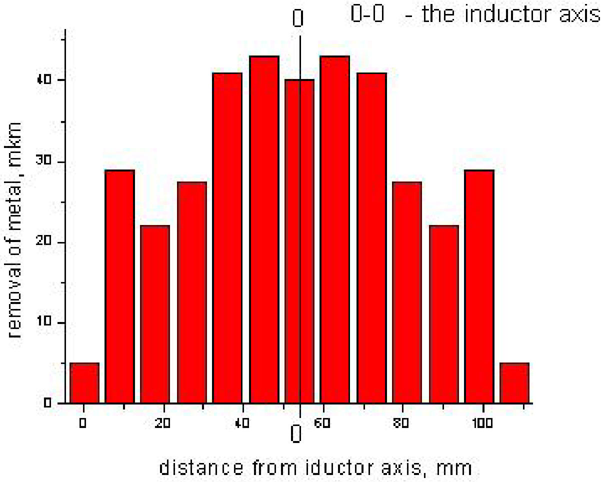


Fig.7. Diagram of allowance removal in aluminum samples

Search of conditions providing for total removal of initial burrs included:

- study of influence of way of powder fillup of working gaps,
- influence of feed rate and speed of inductor rotation;
- value of supplying current,
- composition of magnetic-abrasive powder.

3.2.2 Influence of rotation frequency of inductor.

Changing of rotation frequency of inductor is accompanied by centrifugal force increase. This results in powder thrown-up increase and cutting speed increase. These effects must contrary influence on burr and allowance removal. The obtained results have extremums (see fig. 10 and 11)

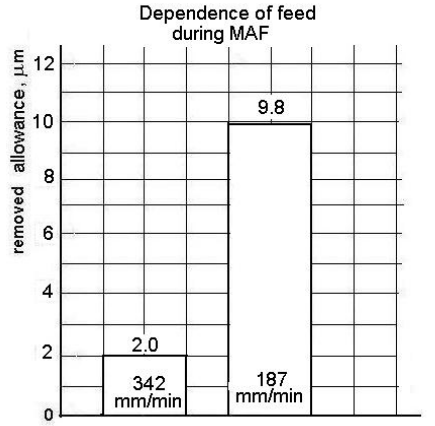


Fig.8 Diagram of allowance removal with different MAF feeds.

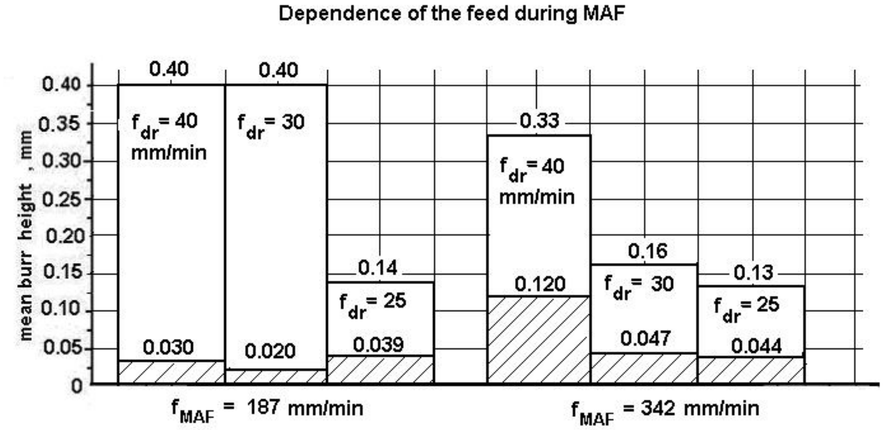


Fig.9 Diagram of burr height with different MAF feeds (f_{MAF} – feed in MAF; f_{dr} – feed during hole drilling)

Cutting speed increased in the range 130...180 rpm. Powder was more actively thrown-out in the range 180...280 rpm.

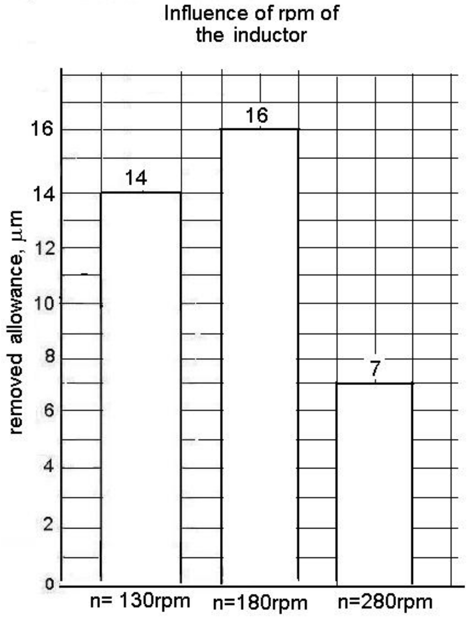


Fig.10 Influence of rotation frequency of inductor on removal rate in aluminum samples

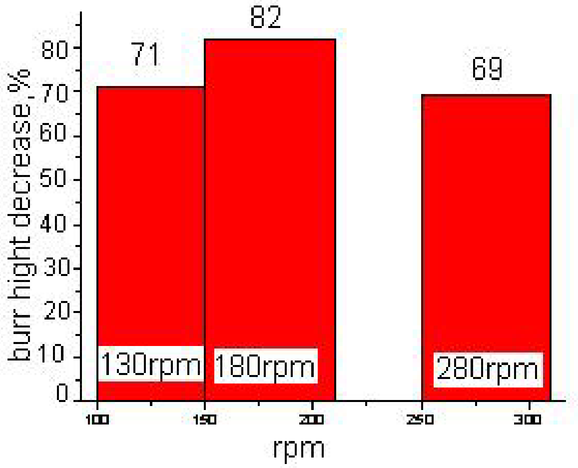


Fig. 11 Variation of burr height (%) at different rotation frequencies of inductor

For finishing of non-magnetic workpieces using this inductor, rotation frequency n=180 rpm is recommended.

3.2.3 Influence of coil current

Two values of current 1.2A and 1.4A were used in experiment. The second value exceeds permissible current for long-continued work of the designed inductor. The results of experiment are shown in figures 12 and 13. Increase of coil current in 1.2 times and corresponding increase of magnetic induction from 0.35 T up to 0.37 T in the external working gap couldn't considerably increase cutting forces and forces to confine powder under poles. Nevertheless increase of current supplying the coil increased allowance removal in 1.4 times. The difference in burr height decrease is negligible. The value of current 1.4 A exceeds permissible for long work value of current for the designed inductor.

Essential increase of magnetic induction for finishing non-magnetic workpieces is possible only by changing construction of poles of the designed inductor.

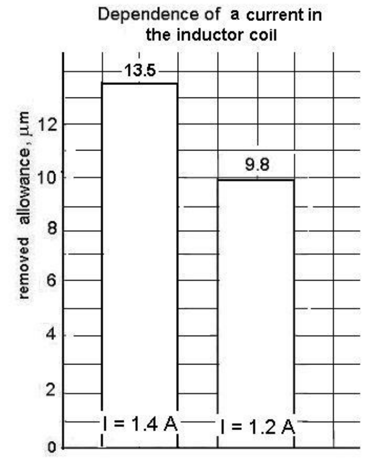


Fig.12 Diagram of allowance removal at different values of current in inductor coil

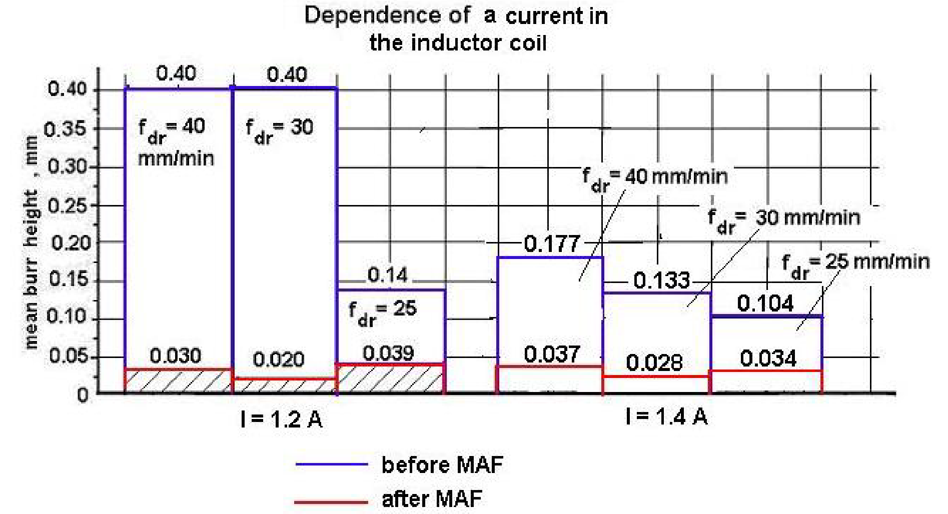


Fig.13 Diagram of burr height variation vs inductor coil current (f_{dr} – drilling feed)

3.2.4 Influence of composition and graininess of magnetic-abrasive powder

In all the experiments described above magnetic-abrasive powder Fe-NbC was used. Its chemistry is as follows: 35% Fe + 65% NbC. Powder graininess is 150/200 mkm.

Attempts to deburr using the same powder but with less graininess were not successful. This powder is good for surface polishing, but not effective for deburring in aluminum samples.

Powder was also tested by its magnetic and abrasive properties.

To this end another powders were prepared:

1. powder of annealed iron GH-3 . Its chemistry is – C- 1%, Si – 0.7%, Mn – 0.74%. Breakup: 0.425 mm –0%, 0.180 mm –65%, 0.125 mm – 30%;
2. composition of iron powder (50%) GH-3 and (50%) of magnetic-abrasive powder Fe-NbC. Chemistry of magnetic-abrasive powder is Fe -35% and NbC 65%. Graininess of magnetic-abrasive powder is 150/200 mkm;
3. composition of iron powder GH-3 (&0%) with abrasive powder Al_2O_3 (30%).

To prevent segregation of compositions №№ 2,3 before work, the last were wetted by emulsion oil. This emulsion oil is usually used for metal cutting.

So comparing compositions of powder the conditions of experiment were selected as follows: coil current - 1,6 A ; magnetic induction in the external pole (gap filled up with air) - 0.40T; - height of the working gap - 2.0 mm; volume of powder - 13 cm^3 ; rotation frequency of spindle – n =370rpm; table feed - f_m= 87 mm/min; duration of finishing - 4 table strokes.

The results of burr height variation after MAF with different compositions of magnetic-abrasive powder are shown in figure 14.

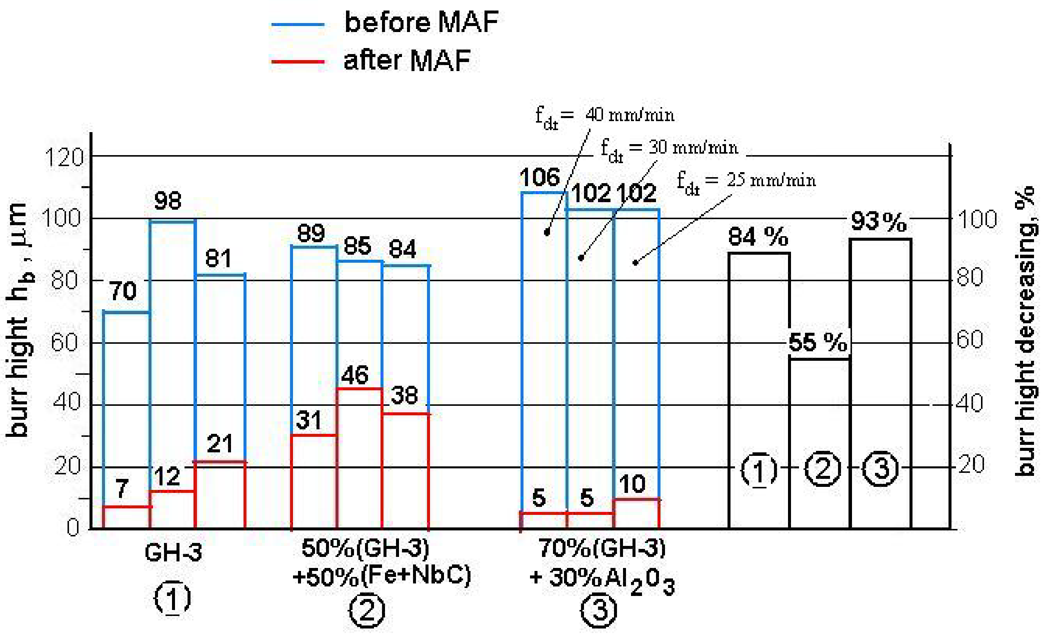


Fig.14 Results of deburring using magnetic-abrasive powders of different compositions

The best result is obtained with powder №3, which has good magnetic and abrasive properties

3.3 Deburring in steel samples

Conditions of experiment:

Material of samples	Steel	Magnetic-abrasive powder	Fe+NbC
Coil current	1,0 A	Powder graininess	150/200 μm
Magnetic induction in external pole (air gap)	0.8T	Powder volume	13 cm^3
Height of the working gap	2 mm	Rotation frequency of spindle	130rpm
		Table feed	f_m= 187mm/min

3.3.1 Influence of rotation frequency of inductor on powder confinement in the working gaps

Magnetic induction in the working gap (0.8T) is enough for creation magnetic forces counteracting centrifugal forces. Rotation frequency was changed in the range 280rpm - 130rpm. The extraordinary behavior of powder was observed: it wasn't thrown-out by centrifugal forces and attracted to fixing plate without following rotating inductor. Apparently, material of plate (or powder) had large coercive force and remained magnetized after magnetic inductor shift. As rotation frequency of inductor decreased in the working gaps the larger amount of powder left.

3.3.2 Influence of samples location relative to inductor axis

Considering steel samples, different parts of finished surface had different time of contact with powder (fig.15). This resulted in full removal of burrs for holes which were on the way of internal pole motion (fig.15). All the other burrs were partly removed.

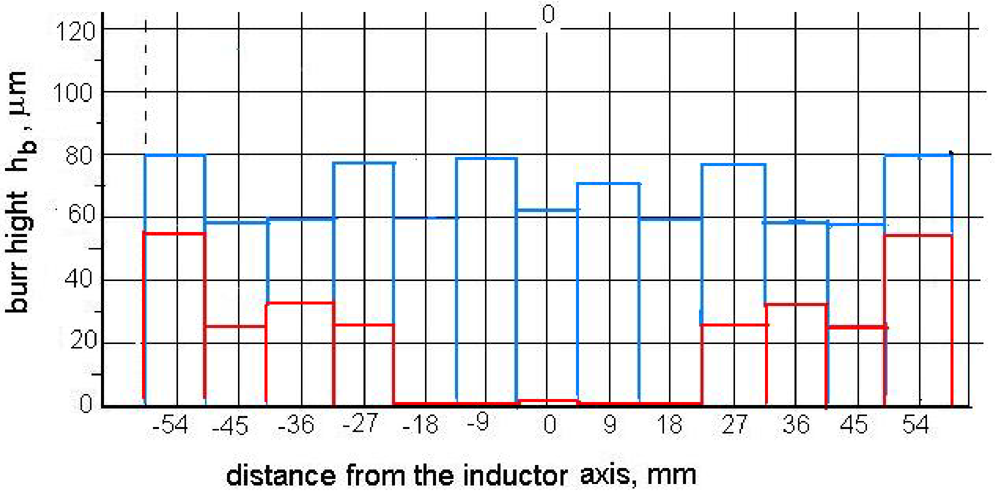


Fig.15. Variation of burr height for steel sample before and after MAF

Average variation of burr height along the finished surface was 60±30% with large value scattering. Variation of burr height in the area equal to diameter of internal pole (50 mm) was 98.5±0.5% (fig. 16).

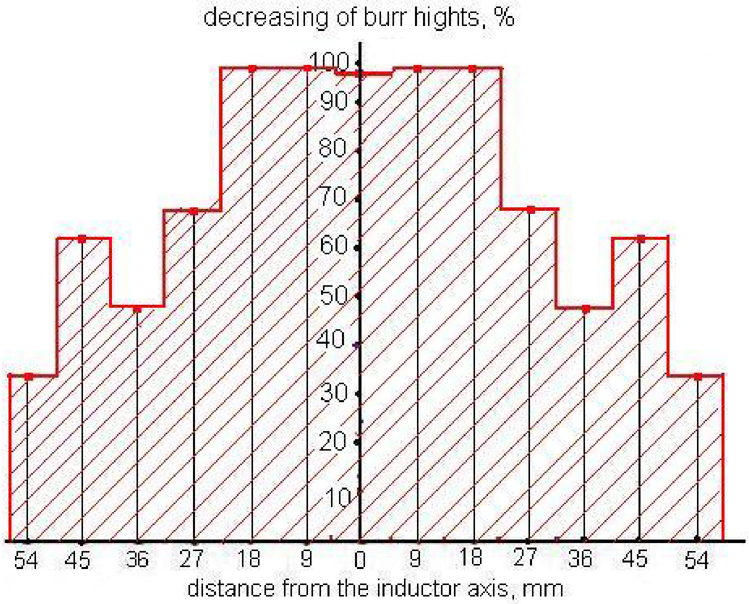


Fig. 16.Percentage burr height decrease during MAF under inductor poles

CONCLUSION

Burrs formed in drilling do usually appear in the final stage of part manufacturing. These burrs have high strength and hard predictability of their shape and dimensions. There are several ways of removal of such kinds of burrs. Nevertheless manual deburring is still going to be used.

Carried out experiments reveal opportunity for productive removal of burrs in large surfaces with drilled holes using MAF. It was shown that this method can be applied both for ferromagnetic and non-magnetic parts. This method can be improved as applied to new tasks of deburring.

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