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THE STATE OF THE ART AND RECENT RESULTS OF MAGNETISM-AIDED SURFACE IMPROVING AND EDGE FINISHING PROCESSES

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ABSTRACT
Denomination Magnetism Aided Machining (MAM) comprises a number of relatively new industrial machining (firstly finishing and surface improving) processes being developed at the present time too. MAM is effective – among others – in polishing, deburring and burnishing of metal parts. The authors give a brief outline of these modern processes, and make an attempt to systematize them. The paper summarizes the results of the experimental research work carried out by the authors mainly in field of magnetism-aided abrasive machining and roller burnishing in finishing and deburring operations.
Keywords: magnetism, finishing, polishing, abrasives, burnishing

1. INTRODUCTION
Traditional finish machining processes can not satisfy current industrial demands for surface finish and efficiency. Presently, it is required that the parts used in manufacturing of semiconductors, atomic energy equipment, medical instruments, aerospace components etc., have a very precise surface roughness and edge condition. In the last 20 years, a number of special finishing technologies have been developed which combine more physical effects (e.g. magnetic, electro-chemical etc.) and machining processes (e.g. abrasive machining, rolling, burnishing etc.) and meet the hardest requirements too. In this paper, we focus on the magnetism-aided (MA) technologies which represent a considerable part of research activity of the Manufacturing Engineering Department of the Faculty of Engineering.

2. SYSTEM OF THE MA-TECHNOLOGIES
The MA-finishing processes had originated in the U.S. in the 1940's, and it was in the late 60' that much of the initial development took place, in Europe and Japan. It was demonstrated that this technique could be applied effectively for the finishing of a wide range of products. In the late 1980's, Japanese researchers have studied the principles of the operation, finishing characteristics under different conditions, and various applications of the MA-processes. The studies have later been extended to design various equipment for external finishing of rods, internal finishing of tubes, finishing of flat and free-form surfaces etc. The Magnetic Float Polishing (MFP) technique was discovered and its equipment was designed in 1990's for finishing nonmetallic (ceramic) bearing balls, based on the magneto-hydrodynamic behaviour of a magnetic fluid. In the late 1990's a relatively new kind of the MA-processes was developed: the Magneto-Electrolytic-Abrasive Polishing (MEAP). This is a compound process for mirror polishing the surface and edge of workpieces made of difficult-to-cut materials. The newest MA-process developed by the authors in early 2000's, is based on the strain hardening of the workpiece-surface rolled in magnetic field, due to the plastic deformation (MA Roller Burnishing, MARB). But it is hoped that the R+D activity in this field could be continued [1].

The system and classification of the MA-processes is demonstrated in Fig. 1. These MA-technologies can be used for finish machining of external and internal surfaces of metallic (both magnetic and nonmagnetizable) and nonmetallic parts of various forms (cylindrical, flat, etc.), and most of them has already been introduced into the industrial production.

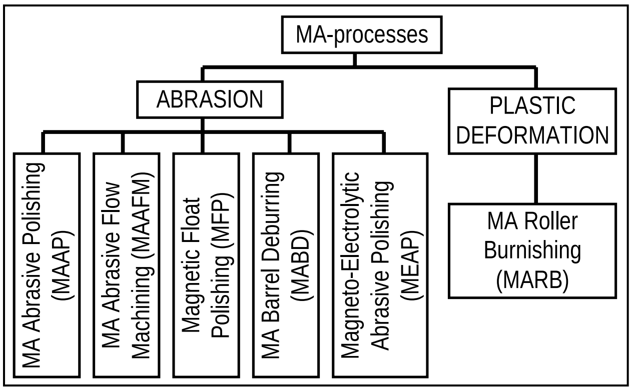

Figure 1. Classification of the MA-processes

3. RESEARCH ACTIVITY IN FIELD OF MA-PROCESSES

3.1. MA Abrasive Polishing (MAAP)

The aim of our research related to the MA abrasive polishing – taking into consideration the industrial demands – was to find the proper technological parameters and abrasive grains for polishing of steel, but hard-chromium-plated cylindrical shafts.

The experimental MA polishing equipment developed by the authors, was adapted to a universal engine lathe (Fig. 2.). The specially prepared N and S poles with $\ell = 2d$, were connected to the electro-magnet which was fixed onto the saddle of the lathe. The electro-magnet was characterized by the following data:

- material of the iron core: low carbon steel,
- cross-section of the iron core: $A_v = 50 \times 70$ mm^2,
- length if the iron core: L = 500 mm,
- diameter of the copper wire of the magnetic coil: 2 mm,
- number of turns: $N_t = 2 \times 800$,
- source voltage: U = 0…40 V and current: I = 0…20 A (adjustable direct current).

In the polishing tests, the shaft was set up between two magnetic poles providing δ gaps between the workpiece and the poles, and it was clamped into the chuck of the lathe and supported by a centre in a tailstock. The gaps were filled with magnetizable, natural or powder-metallurgically processed or iron-coated abrasive grains (Al_2O_3 + Fe or TiC + Fe). With rotating workpiece, the adjustable magnetic force (created between the poles) pressed the abrasive grains to the workpiece with the necessary pressure. The magnetic flux density (B = 0,5…2 T) existing in the working area was measured by MPU-ST-type Hall-detector instrument [2].

The polishing experiments were carried out on shafts of (ø20…ø30) x (70…400) mm size, made of C45-type unalloyed steel with 15…20 μm thick hard-chromium coating. The roughness of the chromium-plated surface (before the polishing tests) was R_a = 0,3…0,9 μm (for the roughness measurements PERTH-O-METER S6P-type laboratory profilometer was used).

Conclusions based on the experimental results:

- The natural (mined) Al_2O_3 + Fe grains have sharper cutting edges than the TiC + Fe grains produced by sintering, thus the material removal rate (MRR) is higher using the former type of grains.
- Surface roughness decreases when finer grains are used, but the productivity will be lower. For finishing cuts finer grains (W_z = 100…300 μm) are recommended.
- With the increase of feed surface roughness will considerably grow.
- The increase of cutting (peripherical) speed decreases the surface roughness.
- The increase of magnetic flux density increases the magnetic force on the grains, thus the MRR also increases, and – tipically in polishing technologies – the surface roughness decreases.
- The increase of polishing time decreases the surface roughness for a while, but further increase will be practically inefficient.
- Gap size has an optimum size. If it is too small, the grains might be stuck, if it is too wide, the magnetic flux density may decrease. The optimum size is: δ = (3…5) x W_z.
- With properly selected process parameters, the surface roughness can be reduced to 25…30 % in one working step (within a double stroke).
- Recommended process parameters: cutting (peripherical) speed of the workpiece:

v = 30…100 m/min, feed rate: f = 0,1…0,6 mm/rev.

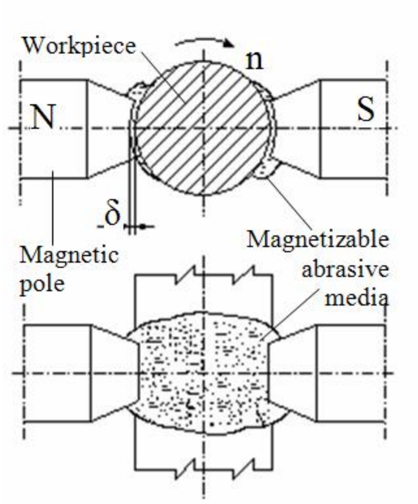

Figure 2. MA abrasive polishing

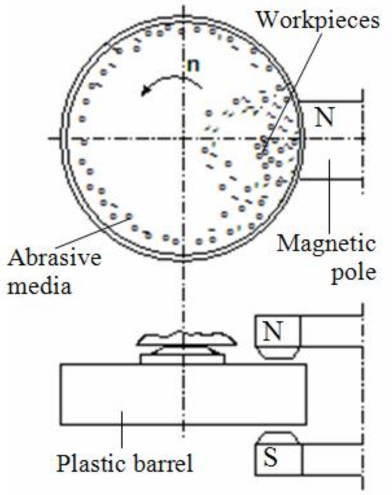

Figure 3. MA abrasive barrel deburring

3.2. MA Abrasive Barrel Deburring (MAABD) and Cleaning

Deburring and cleaning of small size, delicate workpieces used as precision engineering parts (e.g. blanked precision pinions), can be made more effective using MA technology. In the Fig. 3., an MA abrasive barrel deburring machine developed and produced by the authors for a novel, patented technology, is illustrated.

The ceramic abrasive grains and the magnetizable workpieces are placed into a rotating plastic barrel with a horizontal axis. During the rotation, a vortex is created within the barrel, where the workpieces are "flexibly" gripped by the magnetic force. The stationary magnetic field is provided by a direct, adjustable electrical source and magnetic coils. The revolution of the barrel can be changed continuously. The diameter of the barrel of the experimental machine is 300 mm with width of 80 mm. The magnetic flux density in the gap of δ = 1 mm between the barrel and the poles was B = 0,5…1,5 T. The optimal load is 40…60 % of the volume of the barrel, and the rate of the workpiece and abrasive media is 1:3…1:5 in the load. This process can be used for cleaning small parts too [3].

Conclusions based on the experimenta results:

- Appropriate motion of the vortex in the barrel can be achieved by proper regulation of the kinematic and magnetic parameters (rpm of the barrel, magnetic flux density etc.), during machining.
- The rpm of the barrel must be set so as to create the vortex, because it is essential for the abrasive deburring process.
- In case of deburring of sheet metal parts with very fine surface finish (R_a < 0,2 μm), it is advisable to add 1/3…1/4 part lubricating grist or flour to the abrasive media. The grist or flour fills the cavities of the grains, and this way the grains glide over the fine surfaces of the workpieces without scratching them, while the sharp burrs will be removed. The surface of the workpieces can be protected against the harsh scratches if Al_2O_3 balls are used.

3.3. MA Roller Burnishing (MARB)

The MARB is based on a concept that the surface roughness of annealed steel workpieces (HB = 150…300) can be considerably decreased by burnishing in magnetic field usin steel balls (e.g. bearing balls), in addition the surface layer would remarkably increase. The authors have examined this process for both cylindrical and flat surfaces. In case of cylindrical surfaces, the burnishing equipment was developed according to the concept shown in Fig. 4. and was adapted to a universal engine lathe. The setup of the C45-type steel ($HV_{0,04}$ = 220) workpiece was similar as in MAAP tests (see chapter 3.1.). The burnishing action is performed by bearing balls set above or under the poles in radius-shaped slots preventing the balls from any kind of axial

displacement. The magnetic force keeps the balls in the slots and – depending on the magnetic flux density – presses them to the surface of the workpiece with a force of 50…100 N.
In case of flat surfaces, a relative simple experimental MA burnishing equipment was designed and adapted to a vertical milling machine (Fig. 5.). During rolling, the balls are kept between the burnished surface and conical end of the rotating arbor by the magnetic force. In the course of the burnishing tests, a magnetizable (Fe490-2-type steel) and a nonmagnetic (Al-alloy) workpiece material was investigated [4].

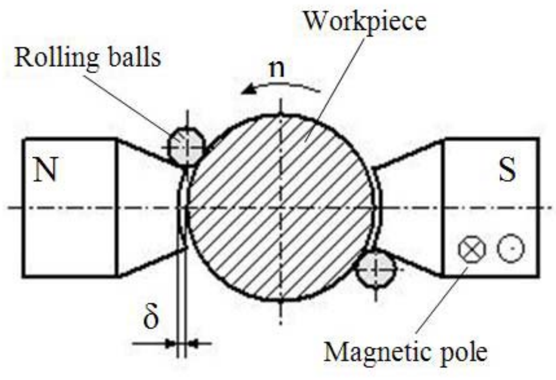

Figure 4.MA roller burnishing of cylindrical surfaces

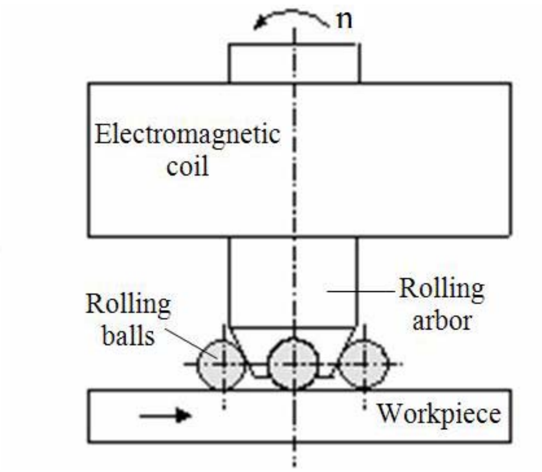

Figure 5. MA roller burnishing of flat surfaces

As a result of the burnishing tests, the following conclusions could be drawn:

- The quality of the MA burnished surface is primary influenced by the magnetic parameters, the circumferential speed, the feedrate and the ball diameter.
- With the increase of the feed and the ball diameter the surface roughness also increases, while the hardness of the workpiece surface layer decreases.
- Surface roughness of the workpiece can be decreased to 25…30 % of the original R_a (surface condition prior to the burnishing tests was fine turned or ground).
- The hardness of the surface layer may considerably (in some instances by 50 %) increase within the depth of 10…50 μm, due to the strain hardening.
- The process is suitable for eliminating fine burrs too from the edges of cylindrical and flat surfaces.

4. CONCLUSIONS

Based on results of the experiments regarding the MA abrasive polishing, deburring and roller burnishing, it has been proved that these processes can be effectively and economically used for finish machining the cylindrical and flat surfaces of metal workpieces, and for deburring of small size, delicate and intricate workpieces (e.g. stampings). During the tests, the effects of various magnetic, geometrical and kinematical parameters on the surface quality, were investigated and determined in detail.

5. REFERENCES

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