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Determination of the working gap and optimal machining parameters for magnetic assisted ball burnishing

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ABSTRACT

This paper presents the results of various experimental analysis regarding a permanent Magnetic Assisted Ball Burnishing (MABB) tool. This type is a special tool using the magnetic field to produce the necessary force for burnishing, it is applicable especially to rolling flat and 3D harmonic surfaces. For the correct operation of this special kind of tool, the set up for optimal distance between the tool and workpiece was introduced also taking into the account the measured rolling force (F_z), which occurs between the tool and workpiece because the magnetic force pulls the rolling balls on a cone which is located at the end of the tool. In this paper the optimisation of the process parameters for burnishing of C45 normalized pre-machined steel is also presented. To determine the dominant machining parameters the resulted surface roughness and the tribological parameters were also anaysed. The evaluation was completed by advanced measuring and IT equipment.

1. Introduction

"One of the most competent surface engineering methods i.e. mechanical treatment, is the burnishing process" [1]. There are several type of burnishing, like roller burnishing [2], ball burnishing [2] or diamond burnishing [3]. There are also some technologies which are similar to them, for example shot peening [4] and not to mention the special processes like laser-assisted burnishing which is able to burnish high hardness (45–60 HRC) metals [5].

Nowadays the ball burnishing processes have become more accepted as a post machining, metal finishing operation [6], the main aim of conventional ball or roller burnishing is to achieve high-quality surfaces. All surfaces of mechanical parts can be considered as valleys and peaks. During the process one or more balls makes plastic deformation on the surface layer. In the case, if this stress is higher than yield strength of the material, the material near the surface starts to flow [7,8]. In this state, there is a possibility that it may lead to plastic deformation of higher asperities contacted, having the modest effect on the surface quality. It may cause severe wearing behavior which thanks to the burnishing processes increase the hardness and decrease the roughness of the machined surface [1].

As the balls moves across the surface of workpiece, the peaks of surface are pressed down into the material and it flows into the valleys between the peaks as it is presented in Fig. 1 [7–9].

Several studies have investigated the effect of burnishing on the workpiece properties (e.g. increasing the residual stress, hardness, corrosion and wear resistance further to enhance the fatigue life and surface quality) [10–12]. Because its's simplicity and economical effectiveness, the burnishing is a widely used cold treatment/machining process. The type of burnishing process depends on the form of the workpiece (e.g. flat or cylindrical). In the paper a newly designed and introduced flat-surface ball burnishing tool was examined. The burnishing of flat or 3D harmonic surfaces needs special tools and/or equipment (e.g. hydraulic hose and pump) e.g. F. Gharbi, S. Sghaier and T. Benameure designed a tool, which consist of four burnishing tools which are adapted in a special tool holders (Fig. 2) [13].

The main problem with most of the burnishing tools (such as in Fig. 2) is their applicability in a CNC machine because it is difficult to place them into the tool magazine, in Table 1. the advantages and drawbacks of various burnishing technologies are compared.

Considering drawbacks of expensive and complicated construction, the authors designed a novel Magnetic Assisted Ball Burnishing (MABB) tool. During the design process, the Magnetism Aided Machining or Magnetic Assisted Machining (MAM) technologies were investigated [14–18], which are relatively novel industrial machining processes. The MAM technologies are mainly suitable for finishing and surface improvements. The MABB tool was developed to reduce the surfaces roughness increasing the surface hardness and deburring the edge of

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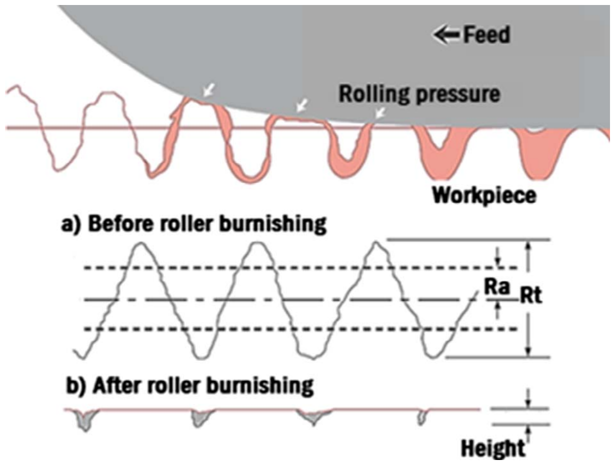

Fig. 1. Evolution of surface by burnishing [7].

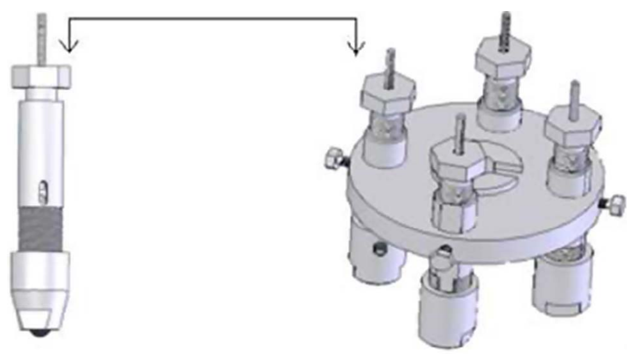

Fig. 2. (A) The simple ball burnishing tool and the (B) tool holder with four ball burnishing tools [13].

Table 1
Cold metal working surface improvement technologies.

Technology	Advantages	Drawbacks
Roller burnishing [2]	Cheap tool	Only cylindrical workpiece
Ball burnishing [3]	Cylindrical and flat workpiece	Expensive tool
Diamond burnishing [4]	Hard workpiece	Rigid tool
Shot peening [5]	3D contoured surfaces	Required special equipment

flat (in some cases even 3D harmonic surfaces) metal parts. The magnetic force makes this process simple, productive and environmental friendly, it is generated by the magnetic field between the workpiece and the tool, so, it is so important to set up the right tool-workpiece distance to ensure the optimal rolling pressure [19].

Several machining parameters, namely burnishing speed, feed rate, force, number of burnishing passes, workpiece material and hardness, ball material, ball size, number of balls and lubricant have to be considered to define an effective and efficient burnishing process [20,21].

Hassan and Al-Bsharat presented in their research that the burnishing forces and the number of tool passes are predominant parameters that have effect on the surface roughness of the workpiece during the burnishing process [22].

Taking into the account that the introduced ball burnishing technology is a novel solution, it has to be positioned among other techniques having similar manufacturing aims (e.g. as in Table 1), moreover it has to be characterized and it's capabilities have to be qualified by various measurements. The analyzed ball burnishing technology improves the tribological features of the machined surface significantly. The most frequently used charcterization features of a surface from tribological point of view are the R_{sk} and R_{ku} roughness parameters, consequently, these quantification measures were used to describe the effectiveness of the proposed ball burnishing soultion. The experiments proved also that a more favourable solution is the application of the rotating dynamometer instead of a multicomponent dynanometer and it can be used for measuring the burnishing force and also in the optimisation of the working gap and the technological parameters, too.

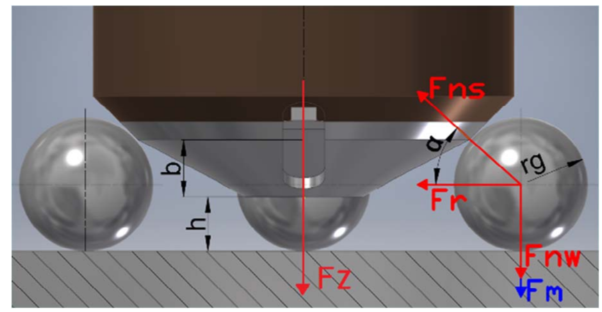

Fig. 3. The generated force during ball burnishing.

2. Magnetic assisted ball burnishing tool

The novel MABB tool contains four magnetizable bearing balls and the magnetic force pulls these balls to a cone which is located at the end of tool and this construction results in the necessary F_z rolling force (F_z in Fig. 3).

The first generation of MABB tools are working with an electromagnet (Fig. 4). The constructions' main advantages are the adjustable magnetic force which gives less importance to the gap distance. But this adjustable function causes problem in the usability, because it requires electric cables feed to the tool during machining, so it is not advantageous to a modern CNC machine. Furthermore, the electromagnetic coil heats up during machining and, as a result, decreases the magnetic field strength [23].

The new MABB tool works with NdFeB permanent magnet instead of the electromagnet (Fig. 5). Thanks to the permanent magnet design, the tool can be placed into the tool magazine, removing edge burr and following the topology of surface.

In a recent study El-Khabeery and El-Axir they identified some of the main effects of the burnishing. Their results are useful and contains essential statements (e.g. the burnishing speed should not exceed about 120 m/min to obtain high surface quality), but as it was mentioned also the tool gap has great significance and so it must be an optimum value [24]. Many further research studies have been conducted to investigate the effects of burnishing feed, speed and force on surface roughness during burnishing process [2,25,26].

High burnishing force is required to achieve low roughness. Because the introduced MABB tool is a novel solution, so, the optimal working gap distance resulting in the highest burnishing force is unknown. This parameter was determined by calculation (Section 3) and experiments (Section 4), too. The experiments consisted in two parts. Since the centrifugal force on the balls decreases the pressure of them to the surface, so, the first test was performed by a standing tool, (first part in Section 4) and in the second paert of the analysis the tool was rotating (second part in Section 4). The search for the optimal machining parameters were done applying the classical Taguchi experimental design method using the already predetermined optimal working gap (described in Section 5).

3. Determination of working gap by calculation

The optimum working gap (h) between the tool and workpiece can