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Surface modification by machine hammer peening and burnishing

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ABSTRACT

A wide range of surface modification processes has been developed over the past decades. Beside the well-established processes such as shot peening, there are other emerging surface modification processes such as machine hammer peening with a potential of applications that still needs to be evaluated. Therefore, all surface modification processes using guided tools with periodic or continuous contact to the workpiece are compared in this paper. After a classification of the processes, the paper presents a systematic description by comparing the different technologies and it explains the proposed standardized nomenclature. It identifies the relevant physical mechanisms of the surface modifications processes and it compares the influences on surface roughness, residual stresses, work hardening and microstructure. One section is dedicated to the need of an accompanying quality assurance. Furthermore, the capabilities of different process simulation approaches are analyzed with respect to process mechanisms and the resulting surface layer characteristics. The service performance such as fatigue life, corrosion resistance, friction and wear are discussed based on best practice results. Finally, the paper discusses the actual and potential applications of surface modification processes: surface strengthening, post welding treatments, smoothing of tools and molds as well as surface structuring and embedding of coating materials.

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1. Introduction and classification of surface modification processes

Many components in industrial practice need to be finished by surface modification processes in order to assure service properties such as fatigue resistance, corrosion resistance and tribological properties. These goals can be achieved by thermal, thermo-mechanical or mechanical surface treatments. The latter, hereinafter referred to as surface modification processes, lead to a plastic deformation of the surface and the material layers beneath it. This in turn changes several characteristics in this area of the component. The intention of the surface modification process may be smoothing or geometric texturing, work hardening, compressive residual stresses or microstructural changes such as phase transformations. Usually, most of these effects occur simultaneously but with different intensities. As a side effect, geometric alterations may occur regarding the entire workpiece. With focus on machining, knowledge about these relations between process parameters, induced surface layer characteristics and service performance was recently collected in a review on surface integrity [101]. This paper will focus on mechanical surface

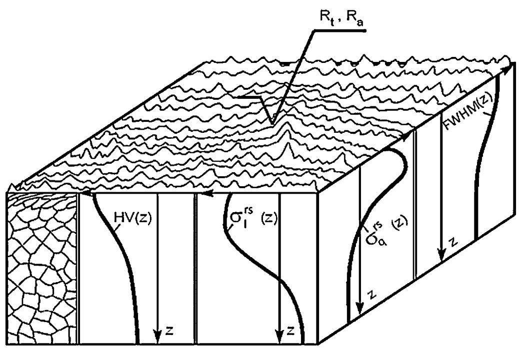

Fig. 1. Surface layer characteristics influenced by surface modification processes, schematically [189].

modification processes aiming at structuring or smoothing the surface topography *Ra* or *Rt*, influencing the state of residual stresses σ^{rs}, achieving work hardening represented by full widths at half maximum of X-ray interference lines *FWHM*, e.g. increasing the hardness *HV*, e.g. or manipulating the microstructure as shown in Fig. 1. Therefore, separating and forming processes on a macroscopic scale are excluded from the paper.

Mechanical surface modification is an ancient technology, originally found in the hammering of helmets and swords during their shaping by craftsmen. The first usage in the modern era also arose from weaponry in the form of gun barrels, but it can be traced

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to the manufacturing of axles and bearing bolts for the railroads as well. It was only in the 1920s and 1930s that surface modification evolved into a separate technical processing method. In particular, burnishing and shot peening were heavily investigated.

Shot peening is a process with an unguided tool and discontinuous surface contact and it was first built on the patent of Tilgham in 1870 [94]. He used sand that was accelerated by pressurized air, steam or centrifugal forces. In the 1920s up to the 1940s more and more industrial applications evolved which proved the effects on fatigue [8,9,60,87,230,236,257], stress corrosion cracking and corrosion fatigue [70].

In contrast, burnishing is based on the continuous and guided contact of the tool with the surface of the material. Föppl established the correlation between burnishing and the increase in fatigue strength in 1929 [55,56,100] and he assumed that this is induced by cold work. These findings were confirmed by Thum in 1932 [220] when he was systematically correlating burnishing and its effects on fatigue strength. He traced these effects back to residual stresses and could also find increased resistance to corrosion fatigue [95,219] and fretting fatigue [221].

In direct comparison to the aforementioned technologies, machine hammer peening (MHP) is a relatively new surface modification process also using guided tools. The first hammer peening application with a guided tool was the Ultrasonic Impact Treatment (UIT). It was developed in Russia for shipbuilding in the early 1970s. It is based on the works of Statnikov [202]. In 1994 the patent was purchased by an American company. In the following years, further ultrasonic hammering systems were invented such as Ultrasonic Burnishing (UB) in 2005 by Bozdana et al. [30] or Ultrasonic Nanocrystalline Surface Modification (UNSM) in 2000 by Pyun [172]. The ultrasonic hammering technology was used to improve the fatigue strength of welded joints and cyclically loaded parts. However, in Europe mostly hand-held pneumatically driven hammering systems have prevailed in industrial practice. These include the pneumatic impact treatment by Schmucker [188] and Gerster [64] and the high frequency impact treatment [57] of Ummenhofer in 2009. Parallel to the development of the ultrasonic hammering systems, Loecker started developing an electromagnetic machine hammer peening technology in 1996 [3] and patented this system in 2007 [131]. Since then, it is mostly used in the surface finishing process of deep drawing tools for the automotive industry. In the following period, pneumatic [238] and piezoelectric devices [123,239] were introduced.

Hammering with guided tools is recently gaining more importance in industrial applications for smoothing of dies, improving fatigue strength and reducing wear as well as increasing corrosion resistance. Since the knowledge of processes with unguided tools such as shot peening is well established and comprehensively compiled [192], the focus here will be on processes with guided tools which are in periodic or continuous contact with the workpiece surface as shown in Fig. 2. Burnishing has no stroke, whereas the machine hammer peening processes

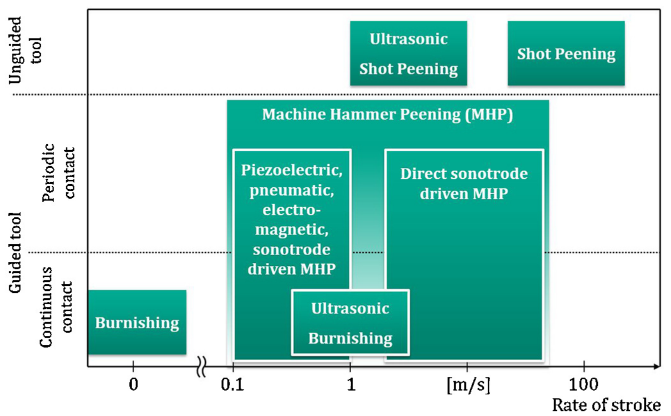

Fig. 2. Overview of surface modification processes with guided and unguided tools.

Table 1
Classification of surface modification processes regarded in this paper and described in literature according to the systematics of Section 2.

Burnishing	Machine hammer peening (MHP)	
	With continuous contact	With periodic contact
• Deep rolling (DR) • Roller burnishing (RB) • Low plasticity burnishing (LPB) • Cryogenic burnishing (CB) • Diamond smoothing (DS)	*Pneumatic (P-MHP)* • Forgefix *Direct sonotrode driven* • Ultrasonic Nanocrystalline Surface Modification (UNSM) • Ultrasonic Cold Forging Technology (UCFT) *Ultrasonic Burnishing (UB)* • Ultrasonic Deep Cold Rolling (UDCR) • Ultrasonic Deep Rolling (UDR) • Ultrasonic Surface Rolling Process (USRP) • Ultrasonic-Aided Deep Rolling (UADR)	*Pneumatic (P-MHP)* • Forgefix • Pneumatic Impact Treatment (PIT) • High Frequency Impact Treatment (HiFIT) *Electromagnetic (E-MHP)* *Piezoelectric* • Piezopeening *Sonotrode driven* • Ultrasonic Needle Peening (UNP) • Ultrasonic Peening (UP) • Ultrasonic Impact Treatment (UIT) • Ultrasonic Impact Peening (UIP) • Rotating Pin Ultrasonic Peening (RPUP) • Ultrasonic Shock Treatment (UST) *Direct sonotrode driven* • Ultrasonic Impact Treatment (UIT)

can be separated on the basis of their different rates of stroke and the different excitation principles. While lower rates of stroke are reached by piezoelectric, pneumatic, electromagnetic or sonotrode driven processes, intermediate stroke rates are achieved by Ultrasonic Burnishing. High rates of stroke are obtained with processes that directly use reached by direct sonotrode driven processes. All treatments using unguided tools are excluded from this paper, as mentioned before, because they are well established and covered by other reviews [192]. The same applies to all similar treatments that are primarily aiming at forming a workpiece such as (rotary) peen forming [184]. Table 1 shows the different processes found in literature and considered in this review. It introduces their classification into three groups: burnishing, continuous machine hammer peening and periodic machine hammer peening. References will be given in Section 2.

An aspect that is not considered in this paper is the integration of the surface modification systems into an external manipulator, which can be done in a CNC machining center, with turning lathes and robots. The manipulation can be performed by multiaxial machines and by using NC-programs [117]. Thus, free-form shaped surfaces can be machined [135,197] in the same setting as the previous (milling) process [239]. In the case of PIT, UIT and HiFIT, the manipulation is performed by direct manual operation.

Following this introduction, the technologies and standardization issues of the processes are discussed. The main part of this paper focuses on the surface characteristics induced by the processes and the resulting enhancement of service performance. Simulation and quality control as well as technical applications are finally presented.

2. Technology of processes

2.1. Burnishing technologies

Burnishing is a cold working process for modifying a surface and to enhance surface integrity. The plastic deformation in the surface layer of the workpiece is achieved by a smooth rolling body with a predetermined geometry which is pressed against the surface of the workpiece.

Based on the type of tool, the burnishing process can be categorized into ball burnishing or roller burnishing. In case of ball

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