Mechanical Investigations on Composite Peened Aluminium

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Abstract. Composite peening describes a novel approach based on the micro peening process. By composite peening, particles can be introduced into near-surface regions of metallic base materials. The proportion of the reinforcement phase decreases gradually with increasing distance to the surface. These so-called Functionally Graded Metal Matrix Composites (FGMMC) are characterised by a multitude of different characteristics, such as material combination, particle density, particle gradient and particle size, and a resulting broad range of properties. The composite material produced by this method promises a high application potential for lightweight, wear resistant and cyclically stressed structural components.

EN AW–1050 was selected as matrix material and alumina as abrasive respectively reinforcement material. Additional abrasives such as silicon carbide and tungsten carbide were also investigated. By varying the process parameters, such as temperature and pressure, the influence on the particle density and the particle gradient was evaluated. Penetration depths up to 30 µm could be observed at high homologous temperatures. The peening process might cause open structures near the surface, the sample were subsequently deep rolled. In addition, this process reduces the surface roughness.

Ensuing mechanical characterisation focused on bending tests. An increase in the flexural strength of the composite material compared to the base material could be observed.

Keywords: Composite peening · Metal matrix composites · Mechanical properties

1 Introduction

Metal matrix composites (MMCs) are characterised by increased specific properties compared to monolithic metals. Due to their low thermal expansion and increased creep resistance, MMCs promise superior properties even at elevated temperatures. Further applications are also conceivable in the field of fatigue and tribology. Since the highest loads often occur locally in a component, the material efficiency can be improved by reinforcing the surface layer. These so-called functionally graded metal matrix

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composites (FGMMCs) have a large number of possible modifications (for instance, material combination, particle density, particle gradient) and resulting properties.

The range of manufacturing possibilities for graded MMCs is large. Therefore, a distinction is made between constitutive, homogenizing and segregating processes [1]. All processes are united by a high degree of complexity in terms of processing. In the best case, subsequent changes are associated with a huge additional effort. Exceptions are coating processes such as laser beam dispersing [2] and cold spraying [3, 4].

Shot peening is used as a standard mechanical surface treatment process. At the beginning of the 1990s, micro peening developed from conventional shot peening with significantly smaller blasting particles [5]. Compared to conventional shot peening, a lower roughness and an increased fatigue strength are achieved [6, 7].

Ando et al. has shown that it is also possible to implement blasting particles into the surface of the target material by micro peening [8]. As a result, the micro hardness could be increased. By heating the target material to high homologous temperatures, it is possible to get the blasting media much deeper into the base material, as the authors have shown with aluminium and tin [9, 10].

2 Experimental

2.1 Materials

In this study, the aluminium alloy EN AW-1050 is selected as the matrix material. The chemical composition of the alloy is listed in Table 1.

Table 1. Chemical composition of EN AW–1050

	Al	Si	Fe	Cu	Mn	Mg	Ti	Zn
EN AW–1050	99.52	0.10	0.30	<0.01	<0.01	<0.01	0.02	<0.01

Alumina, silicon carbide and tungsten carbide are selected as blasting and reinforcement material. The grain size of the blasting material is F600, which is equivalent to a weight-averaged particle size distribution of 9.0 µm ± 1.0 µm. However, measurements with a particle size analyser shows an average particle size of 7.94 µm, 11.86 µm and 21.9 µm for alumina, silicon carbide and tungsten carbide respectively.

The hardness of alumina is 2100 HK according to the manufacturer's specifications. Young´s modulus of the ceramic is approximately 400 GPa for a given purity of over 99.5% [11].

2.2 Experimental Setup

Composite Peening. The composite peening process is shown in Fig. 1. The peening process is carried out with the abrasive blasting system AccuFlo from Comco Inc., which is charged with the blasting material. The peening unit transports the blasting material with compressed air to the blasting nozzle. Preliminary studies with tin and aluminium as matrix material showed that high homologous temperatures favour particle entry [9, 10]. For this reason, a heating device was added to the micro peening system. The temperature of the heating devise is monitored by a control unit. The control unit also regulates the position and speed of the blasting nozzle. Tests are operated by ProNc software from ISEL.

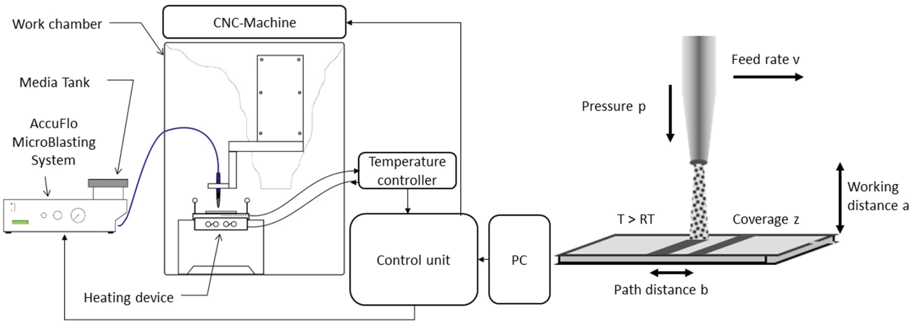

Fig. 1. Scheme of the composite peening system and process (left [10]). Selectable process parameters (right [9]).

Composite peening offers a wide range of process parameters. In addition to the control variables shown in Fig. 1 (right), the nozzle geometry and the angle of the blasting nozzle can be varied. In this work, the process-structure-property relationships of the composite peening process are investigated by varying the temperature, the blasting pressure and the number of operations. The blasting nozzle has a diameter of 0.7 mm and is orientated orthogonally to the sample surface. The working distance of the blasting nozzle is 10 mm. Peening is performed at a speed of 8 mm/s and a distance between the paths of 1 mm. Table 2 lists the investigated process parameters.

Table 2. Process parameters for composite peening

Temperature T	Number of operation	Pressure p
(T/Ts)	(-)	(bar)
0.80; 0.90; 0.95	2; 4	4; 7

Determination of Penetration Depth. The evaluation of the penetration depth is investigated by means of light microscopy and SEM with subsequent evaluation via digital image processing (DIP). The surface roughness is determined using the µsurf confocal microscope by NanoFocus AG. The results are subsequently smoothed with a Gaussian filter of 0.8 mm.

Mechanical Characterisation. Four-point bending tests are performed on an Instron E3000 Electropuls™ (load cell 5 kN) according to ASTM D7264, procedure B. Crosshead speed is set to 10 mm/min. The deflection of specimens is measured via laser triangulation. Force and deflection data are recorded at 40 Hz. The rectangular samples have a width of 5 mm, a thickness of 2 mm and a 40 mm support span. The distance between the loading fins is 20 mm.

Three samples per parameter are tested. The flexural modulus and R_{p02} are determined, the former in a range of $\varepsilon_f = 0.025 - 0.075\%$.

3 Results

3.1 Microstructure

The penetration behaviour of different blasting medias is shown in cross sections in Fig. 2. The process parameters in each case are: $T/T_s = 0.9$, $p = 7$ bar, $z = 10$. The roughness of all surfaces is enhanced by composite peening.

The blasting medium in Fig. 2(a) is Al_2O_3, which is dimpled in the surface layer of the peened sample after composite peening. In addition, porous areas are seen just below the surface. Single particle cannot be identified in the cross section. The penetration depth of SiC is significantly lower, as can be seen in Fig. 2(b). Only a thin layer of ceramic particles covers the surface. During the process, light is emitted due to triboluminescence. In the case of WC, individual ceramic particles can be seen. However, these particles are significantly smaller compared to the initial state (Fig. 2 (c)). Similar to Al_2O_3, the particles are concentrated in individual areas. In addition, pores are apparent between particles and matrix.

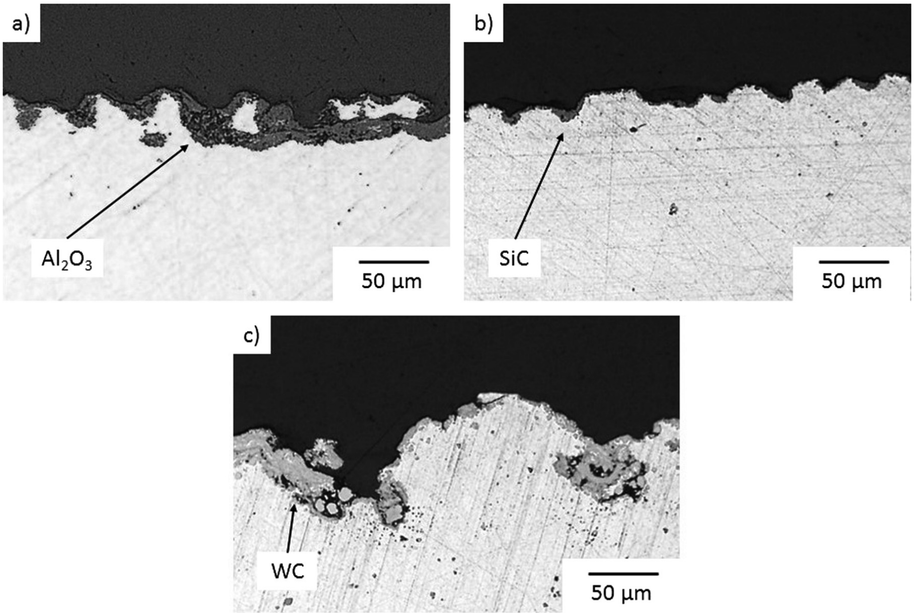

Fig. 2. Surface layer after composite peening with different blasting material. (a) Al2O3, (b) SiC, (c) WC.

3.2 Surface Roughness

Figure 3 shows the surface roughness after processing with various parameters. The surface roughness is increased by composite peening, as can be seen on the left side [10]. Compared to the initial state (R_z = 7.0 µm), the roughness rises with higher coverage and pressure. The influence of the temperature is negligible. A maximum roughness of 18 µm can be measured at a pressure of 7 bar, a process temperature of T/T_S = 0.9 and a fourfold coverage. The results in the right figure show the roughness of the samples after composite peening and subsequent deep rolling. The roughness is considerably reduced by deep rolling in comparison to the composite peened conditions. Thus, a roughness is reached below the initial state. The most relevant influence on the roughness after deep rolling is the process temperature. Lowering the process temperature causes a roughness of 2 µm to 4 µm. In this case, pressure and coverage do not influence the roughness.

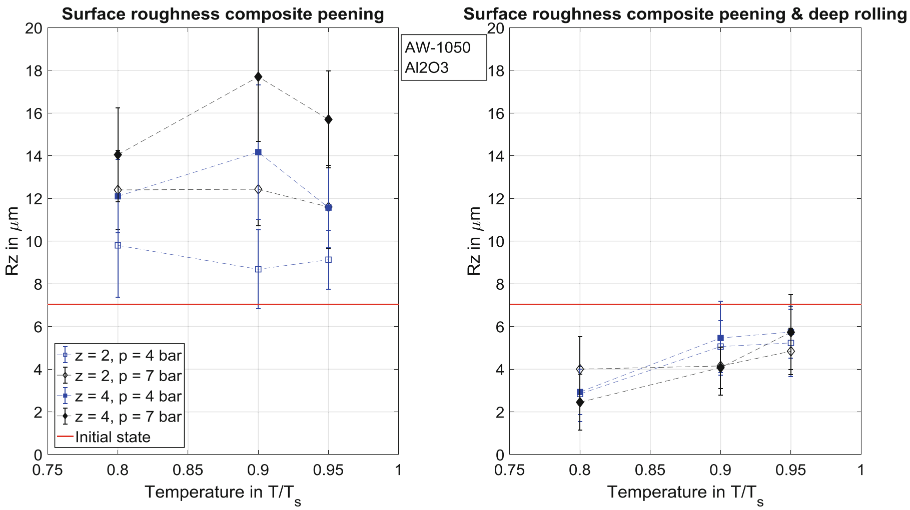

Fig. 3. Roughness R_z after composite peening (left, [10]) and composite peening with subsequent deep rolling (right).

3.3 Penetration Depth

Since the reinforcement phase is concentrated into clusters, it is difficult to determine the influence of the process parameters by the maximum penetration depth. For this reason, Fig. 4. shows the distance to the surface with a percentage of reinforcement of 10%.

Coverage and process temperature have the most prominent effect on the penetration depth of the alumina particles. For instance, at high process temperature of T/T_s = 0.95, the penetration depth can be increased by more than 10 µm with a fourfold coverage. The pressure has an inferior effect on the penetration depth. A minor increase was observed only in the case with a double coverage.

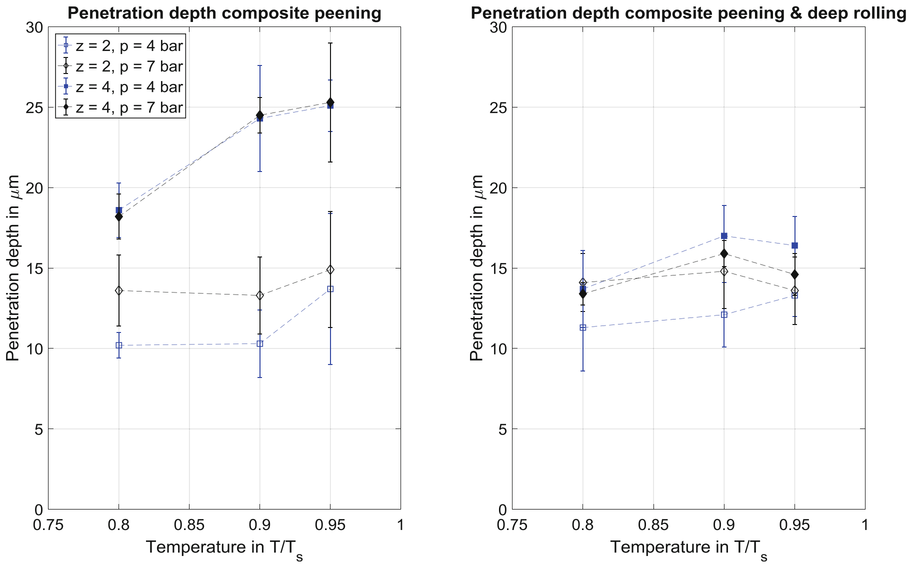

Fig. 4. Penetration depth with a 10% reinforcement ratio after composite penning (left, [10]) and composite peening with subsequent deep rolling (right).

By subsequent deep rolling, the penetration depth is reduced for almost all process parameters. In particular, the penetration depth decreases about 10 µm with fourfold coverage. In contrast, no significant effect of the penetration depth can be observed with a twofold coverage.

3.4 Mechanical Properties

Figure 5 shows the mechanical properties of the composite peened and deep rolled specimens (left: flexural modulus, right: yield strength) from the bending test. No correlation can be observed between the flexural modulus and the process parameters respectively the penetration depth. All values of the flexural modulus range from 67.3 GPa to 73.3 GPa, with almost all standard deviations overlapping.

The yield strength, in contrast, can be increased by a higher process temperature, as shown in the figure on the right. On average, an increase from 107.1 MPa to 113.5 MPa was recorded. Pressure and coverage have no significant impact.

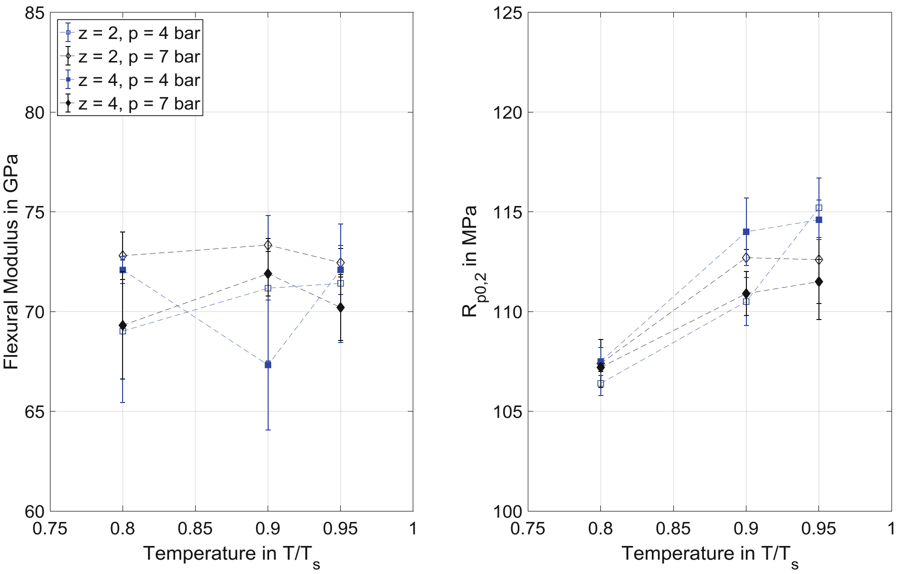

Fig. 5. Mechanical properties of the composite peened samples. Flexural modulus left and R_{p02} right.

4 Discussion

In previous studies the feasibility of introducing alumina particles into an aluminium matrix was demonstrated by composite peening at high homologous temperatures. The roughness of the composite peened surface results from the number of treatments and the peening pressure. The penetration depth is significantly influenced by the process temperature and the coverage.

By subsequent deep rolling, the roughness and the penetration depth, is reduced. There may be two different reasons for this. On the one hand, the pores and cracks that appear after composite peening are closed and on the other hand the surface is compacted and smoothed. Figures 3 and 4 indicate that a high roughness has the most significant impact on the penetration depth after subsequent deep rolling.

An enhancement in flexural modulus due to an increased penetration depth cannot be achieved. Despite the fact that alumina has a significantly higher modulus than aluminium, the thickness of the graded, reinforcing layer (60 µm) is too low compared to the thickness of the base material aluminium (2000 µm). A slight improvement in the yield strength with increasing penetration depth is observed.

The penetration characteristics of different blast media differs considerably. While Al_2O_3 reaches penetration depths of 30 µm in a heated aluminium matrix, only erosion can be observed with SiC as blasting medium. Accordingly, the penetration depth is significant lower. WC, on the other hand, penetrates much deeper compared to the other blasting media. This is probably due to the higher density and the resulting higher kinetic energy of the blasting particles. As already described in [9, 10], the reinforcing particles in the metal matrix of all blasting media are significantly smaller than the starting material. This can be attributed to the impact of subsequently peened particles.

5 Conclusions

The following conclusions can be drawn from the above mentioned studies:

- Ceramic blasting media (Al_2O_3 and WC) can be introduced into the matrix material by composite peening. The maximum penetration depth in the case of Al_2O_3 amounts to 30 μm. SiC cannot be introduced into the aluminium matrix.
- By subsequent deep rolling the roughness can be significantly reduced. Deep rolling also serves as a compaction of the composite peened surface. This reduces the penetration depth measured optically.
- An increase in flexural modulus cannot be observed. The yield strength is increased by a higher process temperature and corresponding deeper penetration depth.

The process-structure-property-relationship for composite peened AW 1050 are shown in this paper. Future research will focus on fragmentation mechanisms of the blasting media as well as further material systems.

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