

Surface roughness analysis after laser assisted machining of hard to cut materials

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Abstract. Metal matrix composites and Si_3N_4 ceramics are very attractive materials for various industry applications due to extremely high hardness and abrasive wear resistance. However because of these features they are problematic for the conventional turning process. The machining on a classic lathe still requires special polycrystalline diamond (PCD) or cubic boron nitride (CBN) cutting inserts which are very expensive. In the paper an experimental surface roughness analysis of laser assisted machining (LAM) for two tapes of hard-to-cut materials was presented. In LAM, the surface of work piece is heated directly by a laser beam in order to facilitate, the decohesion of material. Surface analysis concentrates on the influence of laser assisted machining on the surface quality of the silicon nitride ceramic Si_3N_4 and metal matrix composite (MMC). The effect of the laser assisted machining was compared to the conventional machining. The machining parameters influence on surface roughness parameters was also investigated. The 3D surface topographies were measured using optical surface profiler. The analysis of power spectrum density (PSD) roughness profile were analyzed.

1. Introduction

Among the many advanced engineering materials, SiC reinforced aluminium-based composites and Si_3N_4 ceramics are one of the most important lightweight metals. Mechanical and physical properties of these materials such as high specific strength, very good corrosive resistance and wear resistance indicate that these materials are becoming increasingly attractive for engineering applications [1, 2, 3]. Silicon nitride, as well as metal matrix composites were also successfully applied to sliding elements of cars. However, in general these materials are extremely difficult to cut due to high hardness of ceramics.

One of the possibilities to improve the machining properties of difficult to machine materials is to employ the thermal softening ability of a heat source to heat the material during cutting. The heat source is focused in front of a cutting tool to soften the work piece material, just ahead of the cutting tool, thereby lowering the forces required to cut the material.

The technology of hot machining is not new: the first patent on hot machining was issued before the introduction of high speed steel. Previous generations of this technology employed low-grade heat sources such as electrical resistance, induction and plasma arcs. With the advent of several advanced difficult to cut materials, and with the availability of heat resistant tool materials and cost-effective

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lasers, there has been a renewed interest in this technology. Most of the hybrid machining processes has been developed by combining conventional machining processes with laser beam machining. Successful application of LAM relates to the following advantages: increase in material removal rates, reduction in the occurrence of chatter and catastrophic tool failure, decrease in cutting forces and tool wear, and the capability to cut brittle work materials without extensive cracking. Therefore, laser hybrid machining processes are becoming more popular in industries in recent time. Many attempts have been made to combine LAM with other machining processes. Some of them have been found very effective. The idea of LAM is that laser source of energy is used for softening the work piece material when it is combined with conventional machining processes such as turning, milling, shaping and grinding. In laser assisted turning, the laser heat source is focused on the un-machined section of the work piece directly in front of the cutting tool. The addition of heat softens the surface layer of difficult to cut materials, so that ductile deformation takes place rather than brittle deformation during cutting. This process substantially reduces the tool wear and cost of machining by reducing man and machine hours per part. Chang and Kuo [4] additionally found a reduction of 20–22% in cutting force with a better surface quality during laser-assisted planning of alumina ceramics.

The work described in this paper is the extension of the previous works made by the authors [5, 6, 7] to further understand the process of laser assisted turning.

2. Research range and method

The work piece material consisted of a AlSi9Mg aluminum alloy matrix (composition: 9,2% silicon, 0.6% magnesium, 0,1% iron) to which 20% of silicon carbide with a particle size of between 8 to 15 μm had been added (Fig.1). The investigated material was fabricated by molten metal mixing and direct chill casting by DURALCAN Inc. Material was obtained in the as-cast condition as well as after hot extrusion. The work pieces (cylindrical shape of 10 mm length and 50 mm in diameter) were painted by an absorptive coating each time to increase laser absorption.

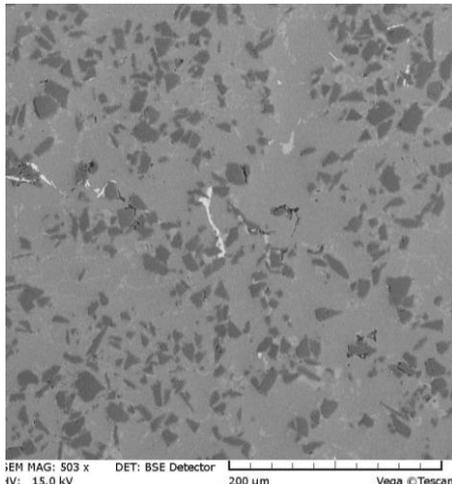


Figure 1. Microscope image of the Al/SiC material microstructure. The SiC particles (have darker colour on the pictures) are distributed through the matrix.

Second research material was hard ceramics Si_3N_4 (2125 HV). The manufacturer of ceramics was Norton Dias (Czech Republic). Experiments were carried out by turning on the TUM 35D1 lathe with infinitely variable adjustment of rotational speed.

Conventional and laser assisted turning tests were carried out using three different wedges:

1. SNMG 120408 MS from fine-grained tungsten carbide KC5510, coated with TiAlN (PVD method), manufactured by Kennametal (USA)
2. SNMG 120408 MS fine-grained tungsten carbide KC5525 with enlarge of cobalt contents, coated with TiAlN (PVD method)

3. SNGN 120708T 02020 from oxide ceramics ($\text{Al}_2\text{O}_3 + \text{ZrO}_2$) AC5 of Kennametal manufacturer (USA)
4. SNGN 120408T 02020 from mixed ceramics ($\text{Al}_2\text{O}_3 + \text{TiCN}$) MC2 of Kennametal Hertel manufacturer (USA)
5. SNMA 120408 from uncoated cemented carbide H10S of Baildonit manufacturer (Poland)

Laser assisted machining was carried out with a 2,6 kW CO_2 laser (2.6kW Trumpf, type TLF2600t). Distance angle between heated area by laser beam and zone of machining was 30 degree in case of MMC (Fig.3a) and 90 degree for Si_3N_4 (Fig.3b).

Machined surface roughness was measured for each trial of experiment. The surface roughness of the turned surface was measured by a Hommel T500 system. The stylus was traced over the machined surface in the direction of feed motion. The arithmetic mean deviation R_a (μm) with cut-off length equaled to 0.8 mm (measuring length was 4.8 mm) was applied as criterion for evaluating the surface finish. The machined surface finish was characterized by the average arithmetic roughness which was determined by the averaging of the arithmetic roughness values for the machined surface roughness profiles at 6 equally angular spaced radial sections on a turned surface. Additionally, images of machined structure topography 3D and power spectrum density of the roughness profile were made on the profile meter Hommel Tester T8000.

Cut zone was heated up by CO_2 laser beam to the temperature $\theta_2 = 1100\text{-}1500^\circ\text{C}$ in case of Si_3N_4 turning.

The selected machining parameters for MMC were: cutting speed ($v_c=100\text{m/min}$), depth of cut ($a_p=0,1\text{mm}$), feed rate ($f=0,04\text{mm/rev}$), work piece diameter ($d=50\text{mm}$), laser beam diameter ($d_l=2\text{mm}$), laser power ($P=300\div 1000\text{ W}$). The temperature was controlled by two Raytek Company pyrometers.

The example of laser assisted turning of ceramics Si_3N_4 was illustrated in figure 2.

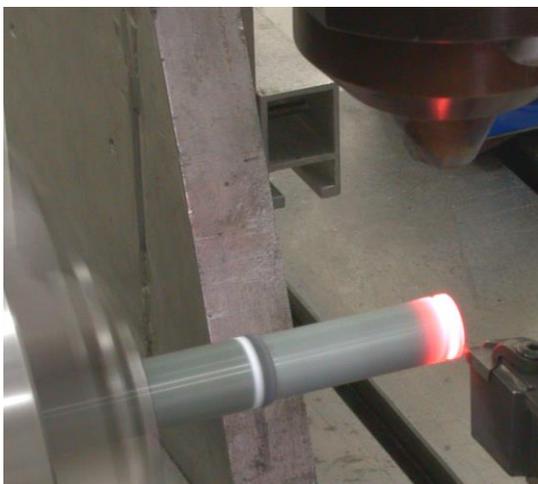


Figure 2. View of ceramics cutting zone area heated by laser.

The scheme of ceramics Si_3N_4 turning set-up was presented in figure 3a and the scheme of MMC turning in LAM conditions was presented in figure 3b.

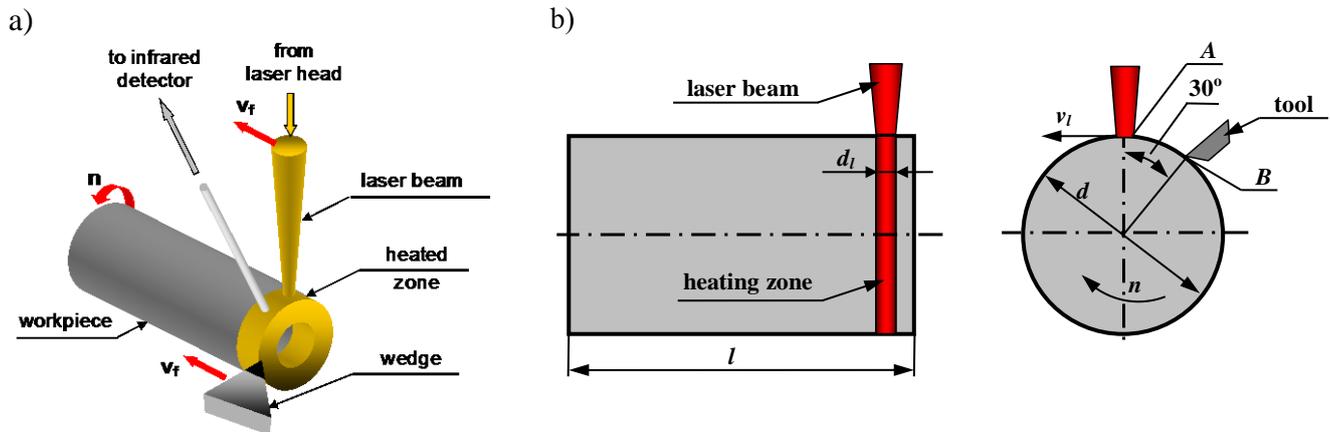


Figure 3. The experimental set-up. a) ceramics turning with LAM b) MMC laser assisted turning, designations: A - heating area by laser beam, B – zone of machining, d - workpiece diameter, d_l - laser beam diameter

3. Research results and analysis

3.1. Metal matrix composites surface analysis

The machined surface roughness is one of the most important quality indicators of hard to cut materials like ceramic and metal matrix composites. For the assessment of the surface quality the average roughness values R_a and R_z were chosen. Figure 4 shows the influence of laser power on surface roughness during turning of Al/SiC MMC.

Figure 5 shows a comparison of the surface profiles of the machined surface by conventional cutting and LAM. The profiles show the difference of surface finish achieved. The significant differences in machined surface roughness have been observed for laser assisted turning and conventional turning. It can be explained that if the cutting zone wasn't heated by laser beam, the SiC reinforcement was pulled out during cutting, cracks and pits were formed on the cutting surface and this caused poor surface finish. Surface roughness produced by LAM is much lower (for all laser power values) than that obtained by conventional turning (Fig.4). As can be seen, for 600 W of laser power, machined surface roughness (described by R_a and R_z parameters) is lower almost 30% than that obtained with conventional turning.

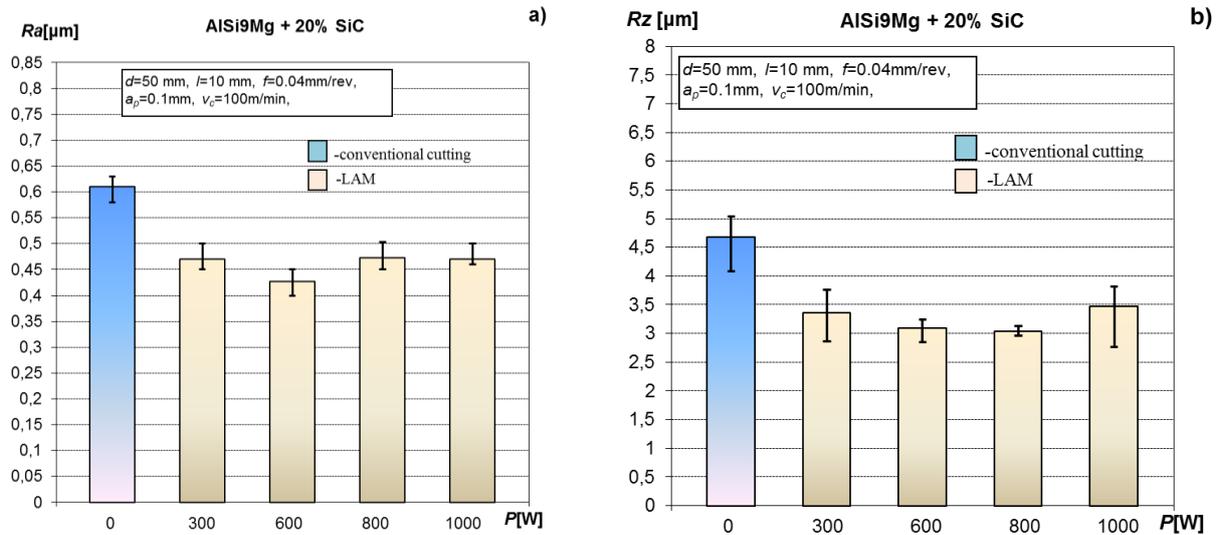


Figure 4. Average surface roughness after conventional turning and LAM of MMC a) Ra parameter, b) Rz parameter

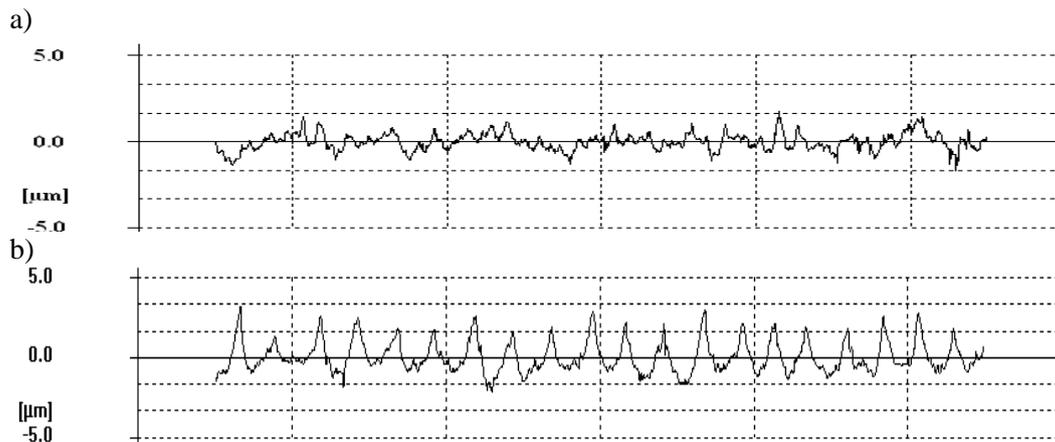


Figure 5. Comparison of machined surface roughness profiles for the same cutting conditions; a) laser assisted turning $Ra=0,39\mu\text{m}$, $Rz=2,71\mu\text{m}$ b) conventional turning $Ra=0,57\mu\text{m}$, $Rz=4,2\mu\text{m}$

3.2. Ceramic surface roughness.

The Si_3N_4 ceramics surface texture after machining is changing together with the laser power density q growth. For the lowest investigated laser power density q the surface profile is determined. In the range of moderate laser power densities q the profile is mixed, however at the highest values of q it has random character (Fig. 6).

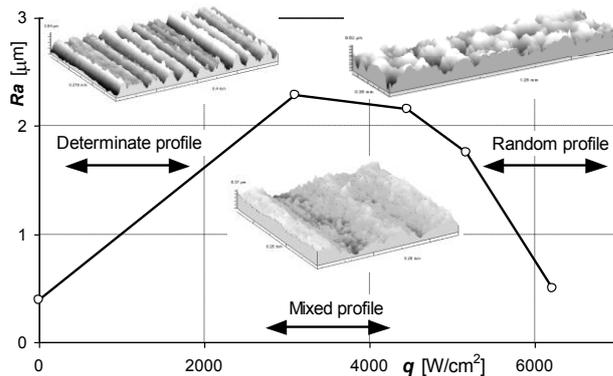


Figure 6. Surface roughness after conventional turning ($q=0$) and laser assisted turning ($q>0$) of the Si_3N_4 ceramics.

The machined surface roughness depends on machined surface temperature (Fig.7). In the ($\theta_2 = 1200\div 1300^\circ\text{C}$) lowest process temperatures Ra parameter values are comparable and not exceeding $1\mu\text{m}$. The machined material become plastic in $\theta_2 = 1400^\circ\text{C}$ temperature. The quality of machined surface is decreasing due to plasticized chips welding phenomena.

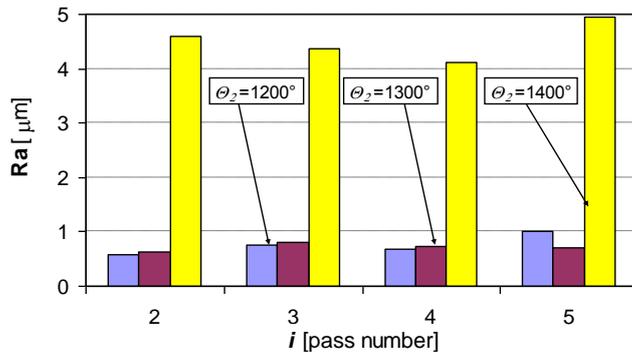


Figure 7. Roughness of Si_3N_4 machined surface. The applied parameters: $v_c = 10\text{m/min}$, $a_p = 0,05\text{mm}$, $f = 0,04\text{mm/rev}$.

Surface texture in the investigated feed range ($f = 0,04\text{mm/rev}$) has a random character without any privileged orientation (Fig.8). This is confirmed by a 3D profile chart (Fig.8a) and, power spectrum density (PSD) chart, which have dominant component different from the applied feed rate (Fig.8b).

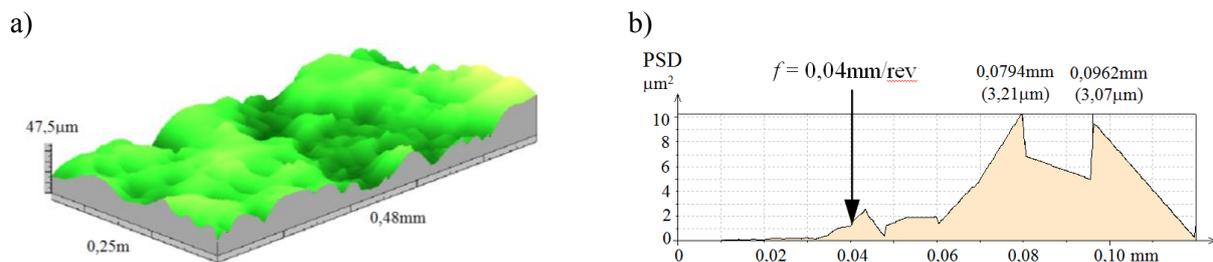


Figure 8. Machined Si_3N_4 ceramics surface texture (a) and power spectrum density of the roughness profile (b) after turning process within polycrystalline diamond (PCD) inserts. The applied parameters and obtained VB_c value: $\theta_2 = 1400^\circ\text{C}$, $v_c = 10\text{m/min}$, $a_p = 0,05\text{mm}$, $f = 0,04\text{mm/rev}$, $VB_c = 0,075\text{mm}$

4. Conclusions

This paper presented an investigation of laser assisted turning effect on the machined surface roughness. The investigation was also focused on the tool wear phenomenon of sintered carbide during turning of Al/SiC metal matrix composites. The above results show that it is possible to benefit

from the integration of laser technology in turning process. The results indicate that laser assisted hot turning improves machined surface roughness in comparison with conventional turning. The method of laser assisted machining MMCs seems to be very promising.

Generation of finished surface machined in a LAM process, in the range of various temperatures shows that machined surface texture has random character with significant disturbances in the cutting edge kinematic – geometric projection. It is probably caused by changes in decohesion mechanism, from brittle fracture to the plastic flow of the ceramics.

The tool-work piece temperature control system during LAM process was very useful, which was proved by carried out investigations.

5. References

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