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Evaluation of tool wear behavior when laser assisted turning of die steel using Nd:Yag pulsed laser

تقييم تآكل أدوات القطع أثناء خراطة صلب العدة بمؤازرة شعاع الليزر النبضى

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ملخص البحث :

إن عملية تشغيل المعادن بمساعدة الليزرتمثل خطوة جديدة واعدة خصوصا للخامات الجديدة التى يصعب تشغيلها حيث أن القطع التقليدى لهذه الخامات يصاحبه تآكل عدة القطع وزيادة قوى القطع بالإضافة إلى خشونة السطح الناتج. إن عملية الخراطة بمساعدة الليزر تعتمد على تسخين الشغلة فى المنطقة التى تسبق عملية القطع مما يؤدى إلى تحسين تشغيل هذه المواد بكفاءة أعلى وبطريقة إقتصادية ويعتبر صلب تصنيع الإسطمبات أحد هذه المواد التى يصعب تشغيلها بالطرق التقليدية.

فى هذا البحث تم دراسة إمكانية تشغيل صلب الإسطمبات DIN 1.2379 بالخراطة بمساعدة شعاع الليزر ذو النبضات بقدرة قصوى 400 W . تم عمل دراسة مقارنة لكل من الخراطة التقليدية والخراطة بمساعدة الليزر بعد قياس كل من عمر الحد القاطع وخشونة السطح الناتج. تم دراسة تأثير تغير كل من سرعة القطع وعمق القطع وقدرة نبضة شعاع الليزر على عملية القطع. أظهرت النتائج العملية زيادة واضحة فى عمر الحد القاطع مع التأثير المحدود على درجة نعومة السطح الناتج فى السرعات العالية.

ABSTRACT

Laser assisted machining represents a new step towards a promissing technique for machining new materials that are difficult to machine. Conventional cutting of such materials is accompanied by excessive tool wear, high cutting forces and poor surface finish. Laser-assisted turning (LAT) offers the local heating of the workpiece before conventional cutting takes place which means improving the ability of those materials to be cut more efficiently and economically. Die steel is an important example of these materials.

In this work laser assisted turning of Die steel DIN 1.2379 is investigated. Nd:Yag pulsed laser head of 400 W power is used to assist the conventional turning operation. For process evaluation, a comparison between conventional and laser assisted turning(LAT) was introduced considering tool life and surface roughness. The influences of variable cutting speed, depth of cut and laser power were discussed. The experimental results showed a considerable increase of tool life as well as a reduced influence on roughness height when using LATat higher speeds.

KEYWORDS
Laser assisted turning (L.A.T), Laser assisted machining(LAM), Nd-YAG laser.

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1. INTRODUCTION

The concept of assisting material removal during machining by heating materials has been used for many years. Low-grade heat sources such as flame, electrical resistance, induction in addition to plasma had been previously used [1].

Laser assisted machining (LAM) of metals uses a high power laser to provide the local heating of the workpiece prior to material removal cutting tool (Fig.1). Rajagopal et al. [2,3] experimented with a 14 kW CO2 laser on titanium and Inconel 718, showing that beam location is important during LAM. LAM provides precise control of deposited energy and heated region, thereby avoiding any undesirable heating of the finished surface. Therefore, it is much more attractive from the viewpoint of ensuring desired subsurface conditions of a machined part.

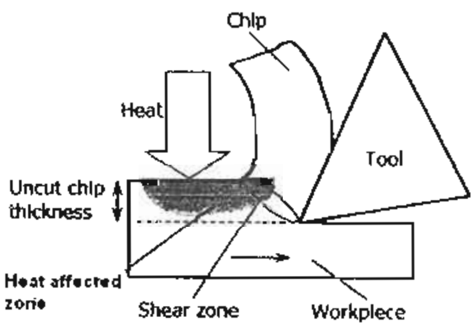


Fig. 1
The concept of laser assisted machining (LAM)

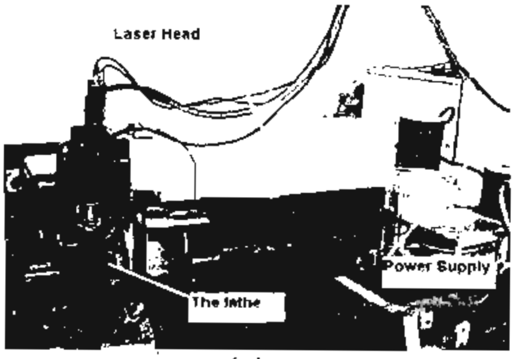
Advantages of LAM also include the increase in metal removal rates and reduction in the occurrence of chatter and catastrophic tool failure. Different researchers have also reported a decrease in the cutting force components, increase of tool life, and improvement in the capability to cut brittle materials without extensive cracks [4]. LAM was reported in cutting different materials such as; ceramics, nickel alloys and materials with a tendency to strain hardening like austenitic stainless steels. In the research carried out by Klocke F.and Zaboklicki A.[5], they found a considerable increase in tool life during laser assisted machining of hot pressed silicon nitride ceramics.

Another work by Lei et al.[6] investigated the metallurgical properties of the material in the shear zone. Increased mobility of the rod-like silicon nitride grains by a reduction in the viscosity of the irregular glassy phase at elevated workpiece temperatures which lead to improvement in cutting conditions. Incropera, F.Pet al [7,8] found a significant difference between tool wear values for the unassisted and laser assisted machining of mullite ceramics with uncoated K313 inserts. They also attributed the mode of tool wear to be adhesion and they proposed that there is an optimum temperature range where flank wear is minimum. LAM of an alumina reinforced aluminum metal matrix composite was studied by Wang [9],and he reported that LAM reduced cutting forces by 30–50% and reduced wear of the carbide tool by 20–30% during the machining. In the work by Khan [10] and Dumitrescu et. Al. [11], diode laser was used in cutting AISI D2 steel. Reduction in tool wear and increase in tool life were observed.

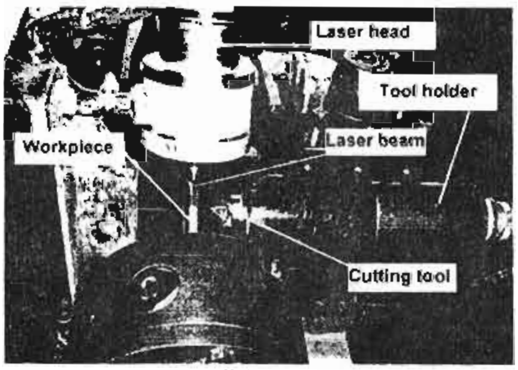
Die steel DIN 1.2379 is the focus of this work. It has excellent wear resistance and deep hardening characteristics therefore; it is widely used in the manufacture of blanking and cold forming dies. Laser-assisted turning (LAT) of this Die steel is investigated using pulsed laser source. The influence of different operating parameters when using LAT was investigated.

2. EXPERIMENTAL WORK

The experimental arrangement was prepared using Nd:Yag pulsed laser head type JK702H by GSI LUMINICS with maximum power of 400W (Fig.2).



(a)



(b)

Fig.2 Experimental arrangement of laser head for LAT

A conventional lathe MDL with 1.3 KW motor power and stepped spindle speed gear box was utilized for LAT process. During the turning process, the direction of laser beam was inclined to the axis of the work piece(fig.3) to prevent the interruption of beam by the chips formed at the cutting point.

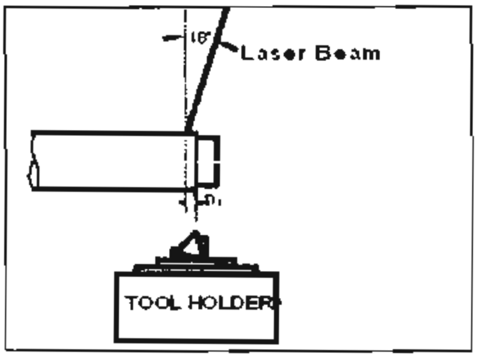


Fig. 3

Laser beam inclination angle and beam spot position on bb workpiece during LAT

Coated carbide tools of grade GC3015 (by SANDVIK®) with nose radius 0.4 mm and setting angle of 45° were used. During each experiment a fresh cutting edge was used. Cutting forces were recorded during each cutting process using a three component dynamometer. Tool life was measured using optical microscope type OLYMPUS BX41M with magnification up to 1500 X. The average surface roughness height (Ra) was measured using surftest SV 402 manufactured by Mitutoyo (Japan).

Die steel specimens with length 120 mm and 20 mm diameter were prepared with the chemical composition shown in Table. 1. The measured average hardness for the prepared test specimens was 56 HRC.

Table. 1 Chemical composition of Die steel DIN 1.2379

Chemical composition	C	Mn	C.	Si	V	Ni	Mo
Weight (%)	1.55	0.4	11.8	0.3	0.6	0.3	0.8

In order to generate a uniform temperature during LAM, it was necessary to match a preheat time of 5 sec by the laser beam, so that, the steady-state temperature is achieved on the work surface at the end of preheat time. The determination of optimum laser beam setting position based on measured minimum thrust force is shown in fig. 4.

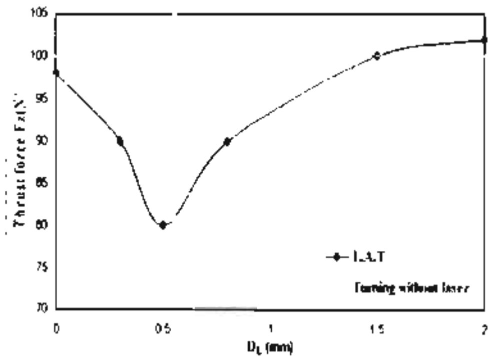


Fig.4
Determination of optimum beam setting distance position

3. RESULETS AND DISCUSSIONS

Comparison of tool wear behaviour at 900 r.p.m with different laser power are shown in Fig.5,6. Initial tool wear is slightly the same at the beginning, but it progresses slowly during L.A.T, leading to the increase of tool life specially for high laser power. This could be explained by the softening of the material in the primary shear zone. During conventional turning , tool life was corresponding to a cutting length 822mm till end of tool life while this cutting length reached 2000 mm when using 300 w laser power (considering tool life criterion a flank wear of 450 µm). It was found that lower laser power density was not enough to reduce the strength in the immediate vicinity of the shear zone by thermal softening.. The flank side of the insert was abraded by hard carbide chromium particles in the die steel. The flank wear progresses more slowly with increasing laser power and accordingly tool life was considerably extended .

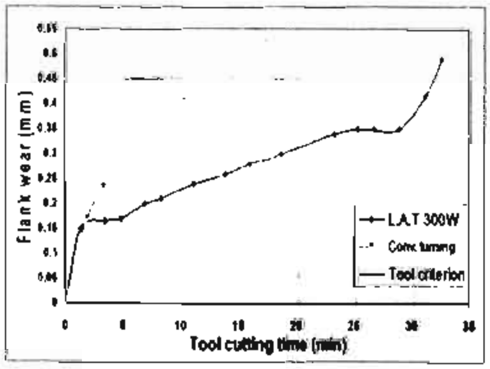


Fig.5
The influence of laser power on flank tool wear

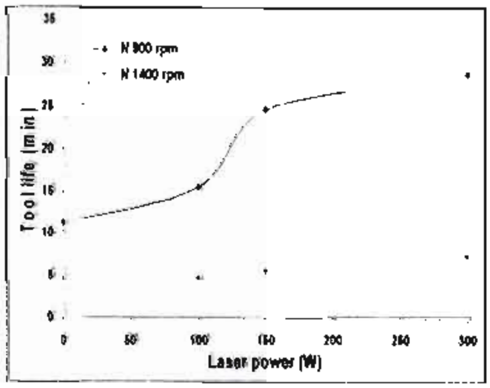


Fig.6
The influence of cutting speed and laser power on tool life

Different combinations of speeds and laser power were used to find the best conditions for the inserts.

Fig.6 shows the tool life obtained at different laser power and spindle speeds. It was found that at 900 r.p.m with a laser power of 300W an increase in tool life by 140% was obtained, while at 1400 r.p.m. a 75% increase in tool life was obtained. The increase of cutting speed must be accompanied by an increase in laser power density to obtain a better tool life.

At different values of depth of cut using different laser power, It was found that power density was not high enough with increasing depth of cut to reduce the strength in the immediate vicinity of the shear zone by thermal softening. Lack of thermal softening of workpiece when increasing depth of cut, results in a slight increase of tool life for L.A.T.as shown in fig.7.

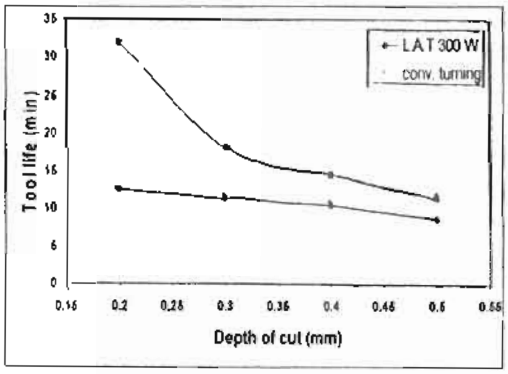


Fig.7
The influence of depth of cut on tool life for both conventional and LAT

Tool crater wear and flank wear are also observed for both conventional turning and LAT at the same cutting conditions (Fig. 8). The material adhesion on crater side is noted to be reduced in LAT. The hard carbide particles from work material will abrade the flank side of tool insert with a higher rate. In conventional turning tool damage is also observed (Fig.9)

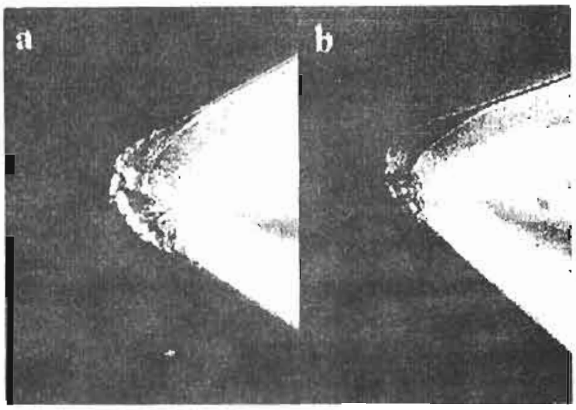


Fig.8
Crater wear on tool face in both conventional turning and LAT
a) conventional turning at N 900 r.p m and t 0.2 mm after 12 min
b) L.A.T at P 300 W, N 900 r.p.m. and 0.2 mm depth of cut after 32 min

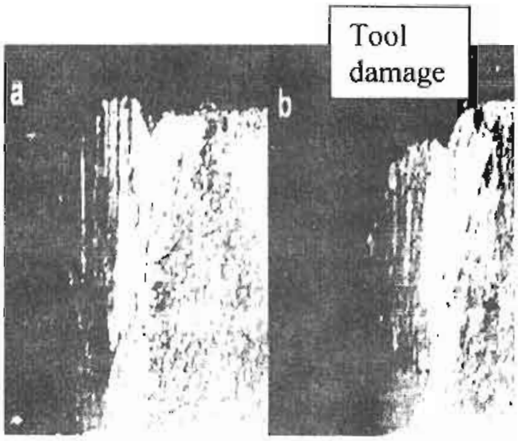


Fig.9
Tool flank wear in both conventional Turning and LAT
a) LAT at 300W laser power,900 rpm and 0 2 mm depth of cut after 32 min.
b) Conventional turning at 900 rpm and 0.2 mm depth of cut after 12 min.

The increase of laser power at a particular cutting speed will increase roughness height as shown in Fig.10 This can be explained by the increase of ability of the material deformation at higher temperature with the increase of laser power. The cavities and side flow which are unavoidable phenomenon happening during LAT are shown in Fig.11,

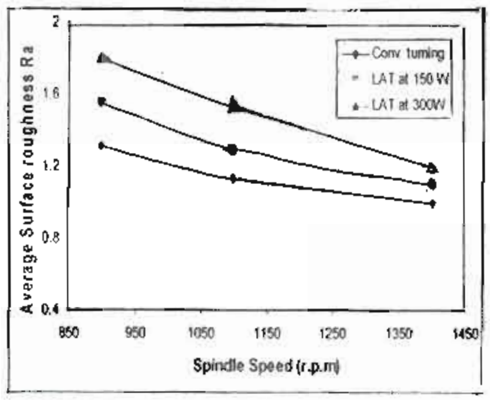
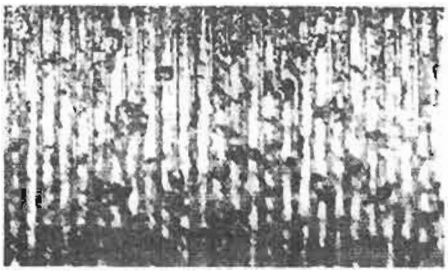


Fig.10
Effect of LAT operating conditions On average surface Roughness (depth of cut 0.2 mm, and feed 0.08 mm/rev.)

(a)



(b)

Fig. 11
a) Material side flow at N 900 rpm and laser power 300W
b) cavities resulting from the broken carbides removed from the matrix

however their appearance and density depends on the cutting speed and laser power. Material side flow is more obvious compared to any other phenomena at higher laser power. This explains the increasing effect of plastic deformation on the workpiece surface such that the material flows on the sides of the feed mark ridges, which can result in a higher surface roughness. Initial surface finish produced with sharp tool is of the order of 0.50-0.60 µm as was recorded during the experiments. However, as the tool wear progress the surface roughness values increases.

We can conclude from Fig.10 that at higher cutting speeds the influence of laser power on roughness height is reduced due to the lower rate of material softening and its influence on side flow pattern.

4.Statistical treatment of experimental results

Minitab -15 software was used to construct 3D graphs showing the combined influence of laser power, rotational speed and depth of cut on tool life (Fig.12, 13).

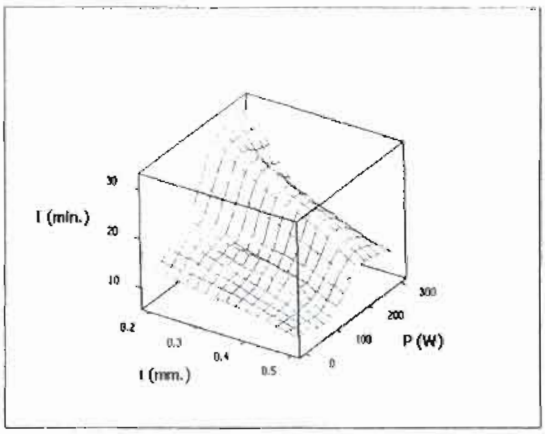


Fig. 12
Influence of laser power and depth of cut on Tool life (at 900 rpm and feed rate 0.08 mm/rev.)

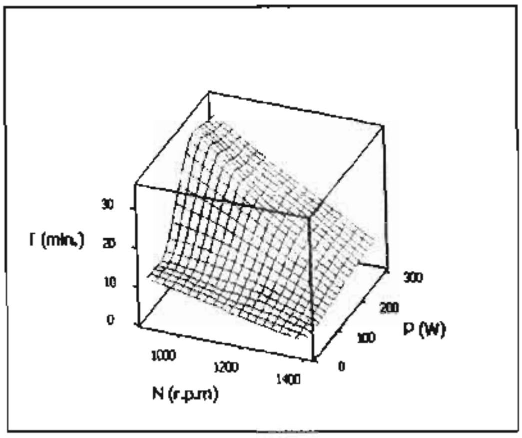


Fig.13
Influence of laser power and spindle speed on Tool life (at depth of cut 0.2 mm and feed rate 0.08 mm/rev)

Also the contour plots for determination of the tool life using different operating parameters are presented (Fig.14,15). The contour plots construction was based on the determination of the regression equations using Minitab-15, by introducing the experimental results .

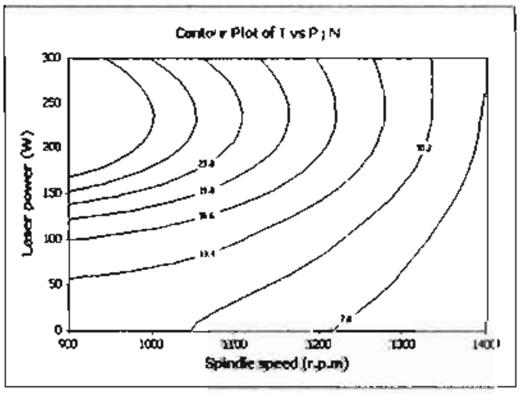


Fig.14
Contour plot for determination of toolife by selecting both spindle speed and laser power
(at depth of cut 0.2 mm)

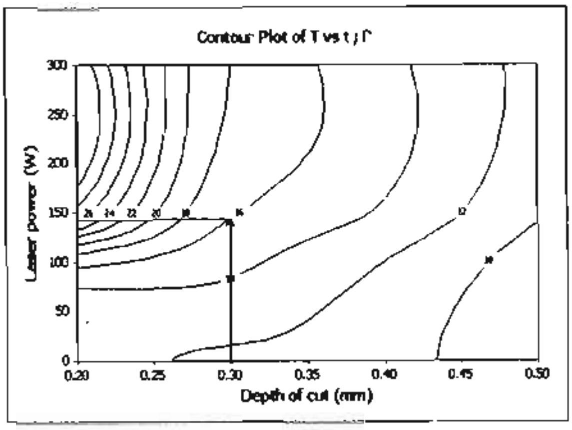


Fig.15
Contour plot for determination of tool life by selecting both depth of cut and laser power
(at spindle speed 900 r.p.m)

The obtained contour plots can be used for the determination of suitable operating parameters for a prescribed value of tool life. The average correlation factor obtained when using this procedure can reach 0.95.

4. CONCLUSION

In this work, laser assisted turning process of hardened Die DIN 1.2379 steel using Nd:Yag pulsed laser has been investigated. From the obtained results we can conclude that:

- The increase of tool life using LAT can reach 250% and more using higher cutting speeds accompanied by higher values of laser power.

- The increase of depth of cut can represent an obstacle for material softening and consequently the increase of tool life is limited. The increase of depth of cut must be accompanied by increasing laser power.

- The average roughness height (R_a) increases when using higher laser power as the mechanism of surface formation is much influenced by the rate of material softening which is followed by side flow on tool feed marks. At higher rotational speeds the influence of laser power on roughness is reduced as it is accompanied by low rate of material softening.

- The contour plots which are obtained from the statistical treatment of experimental results are useful for determination of suitable operating conditions when using LAT with an accepted correlation factor.

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