Laser Assisted Turning of ANSI M2 High Speed Steel

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Abstract
The machining and rework of hardened High speed steel punches and dies used in the metal stamping industry has always been a challenging task. The hardness of the punch and die elements usually range from 58 to 64 HRC and used to be an expensive and time consuming process. This paper aims at comparing the traditional hard turning process with the Nd:YAG laser assisted turning of hardened AISI M2 grade high speed steel using Cermet inserts on a conventional Engine lathe. Cutting forces and surface finish are compared with conventional and laser assisted turning. The work shows the benefits of Laser assisted machining (LAM) over conventional hard turning process.

Keywords
Laser assisted turning; LAM of ANSI M2 steel; LAM using Cermet inserts; Nd:Yag assisted turning; LAM using toolroom lathe; LAM of HSS;

I. Introduction

The need for low wear, high temperature resistant materials such as ceramics, hardened steels and super alloys is increasing day by day. Their applications include aerospace, military and civilian use. These materials pose a real challenge when it comes to machining them. Traditionally machining of hardened High speed tool steels has been done using grinding machines [1, 2]. Complex geometry needed CNC grinding machines, this was expensive and time consuming. The machining can also be done using PCD and CBN cutting tools, but this was limited to very low depth of cut and feed rates.

The use of laser in machining has been studied in several works. Laser assisted machining has been investigated using several materials such as, AISI D2 steel [3-4], AISI 5210 steel [5], Waspaloy [6], Metal matrix composites [7], ceramics [8-12], Magnesium alloy [13], H13 hot work mold steel [14] and hardened steel [15-16]. This paper aims to find a solution to machine one such material which is AISI M2 grade High speed steel. This material is widely used in the construction of sheet metal stamping dies. The stamping dies are used to manufacture sheet metal components ranging from the tiniest of a watch component to the huge vehicle chassis component.

Afshin Panjehpour et al. [17] investigated the use of pulsed Laser assisted machining of AISI 52100 bearing steel. The material removal temperature, specific cutting energy, surface roughness, microstructure, tool wear and chip formations were investigated.

V.N.Gaitonde et al. [18] investigated Laser assisted machining of AISI D2 tool steel and studied the effects of depth of cut and machining time on machining force, power, specific cutting force, surface roughness and tool wear. Ramesh Singh et al. [9] investigated the use of hybrid Laser assisted micro machining of H 13 mold steel using a solid state Laser with miniature cutting tools.

Satyanarayanan Raghavan et al. [4] used LAM to investigate tool wear performance, cutting forces and surface finish of Cubic boron nitride tools and low cost ceramic tools in machining AISI 52100 steel. He concluded that LAM resulted in high cutting speeds, higher material removal rates and comparable surface finish.

Omar Abdulghani et al. [19] investigated the use of modeling and simulation of LAM using Finite volume method on Fluent software. He also compared the results with published data. Hongtao Ding et al. [20] investigated the effect of Laser assisted machining on surface quality and subsurface integrity in terms of surface finish, size control, micro-hardness, microstructures and residual stresses.

II. Methodology

A. Experiment Setup

Laser assisted turning experiments were performed on a 1.6kW GEEDEE WEILER engine lathe. One Nd: YAG laser was used to irradiate the work piece continually ahead of the tool at about 1.5mm. The solid state continuous wave Nd: YAG laser of power 2kW of wave length 1.06µm irradiated the work piece surface 90° circumferentially ahead of the cutting tool and its beam was delivered by a fiber optic cable through a lens to a spot size of 1.5mm. The Cermet insert made by Sumitomo grade T2000Z-CNMG432ELU was used in the experiment. The insert had a tool nose radius of 0.8mm.

The work piece used in the experiments were solid Ø19.0mm shafts made of AISI M2 tool steel hardened and tempered to 54HRC. Prior to the LAM test the work piece was lightly scrubber with emery and the residual heat treatment slag was removed to increase the absorption of the laser energy. The chemical composition of AISI M2 tool steel is shown in Table 1.

Table 1: Chemical Composition of AISI D2 Steel

Element	C	Mn	Si	Cr	Ni	Mo	V	Co	Cu
Weight %	1.4 - 1.6	0.60	0.60	11.0-13.0	0.30	0.7 - 1.20	1.10	1.00	0.25

A constant depth of feed of 0.35mm was used throughout the experiment in order to evaluate the other parameters such as force. The force data was collected using a three component Kistler dynamometer using Dynoware software during LAM. Temperature measurements were performed using a Dual wave length infrared pyrometer. The tool wear was examined with optical microscope. The surface roughness was measured using Marsurf surface profilometer.

Arithmetic average surface roughness Ra was recorded along the axial direction for each pass of the LAM. Surface hardness was measured using Rockwell C scale digital hardness tester.

Fig. 1 shows the experimental setup of LAM on the lathe. The Laser head is mounted on a light weight fixture. The fixture can be conveniently adjusted to several angles and distances to adjust the laser spot position relative to the cutting tool position.

The fixture was fabricated using Aluminum alloy. It has an adjustable base which can be used to focus the Laser beam at the desired angle on the work piece relative to the tool position. The two sliders allow the positioning of the Laser point just ahead of the cutting tool and to adjust the focal distance of the laser to adjust the spot diameter.

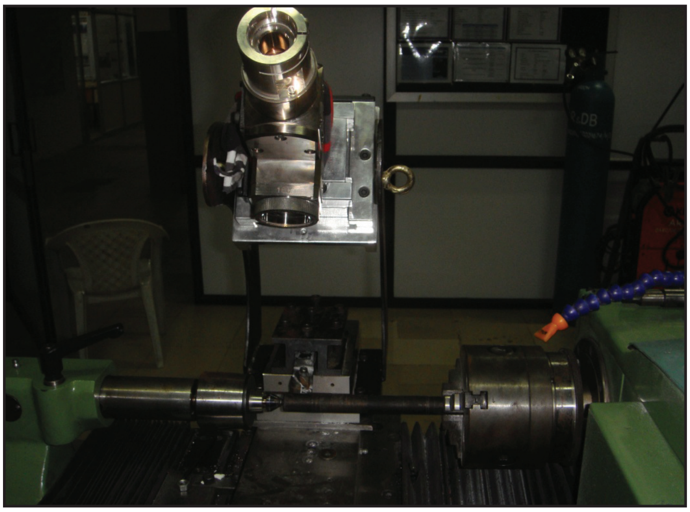

Fig. 1: Experimental set up of LAM

B. Design of Experiments

The experiments were conducted as per the Table 2 below. Laser scan speeds of 75, 100 and 125mm/min were used in combination with laser power 650, 750 and 850W. Feed rates of 0.05, 0.10 and 0.15mm/rev were used to arrive at the scan speeds.

Table 2: Design of Experiments

EXP. NO.	SCAN SPEED (mm/min)	Feed (mm/rev)	LASER POWER (W)
1	75	0.05	650
2	75	0.1	750
3	75	0.15	850
4	100	0.05	750
5	100	0.1	850
6	100	0.15	650
7	125	0.05	850
8	125	0.1	650
9	125	0.15	750

III. Results and Discussions

LAM machining results of the hardened AISI M2 tool steel of 58 HRC are shown in Table 3.

Table 3: Results of Experiment Using Lam

EXP. NO.	LASER SCAN SPEED (mm/min)	LASER POWER (W)	RESULTANT FORCE Fr (N)	Ra (µm)
1	75	650	202.9	0.2223
2		750	124.2	0.2838
3		850	129.6	0.6665
4	100	750	255.7	0.8841
5		850	104.4	0.2463
6		650	150.5	0.1874
7	125	850	285.4	0.3134
8		650	319.85	0.5355
9		750	202.8	0.3342

At 850W of laser power the results show a reduced Resultant force. At 650W of LASER power there is a significant increase in the Resultant force. When the scan speed is high (125mm/min). There seems to be less Laser penetration and hence lower softening of the underlying layers of material hence a large force is required to machine the material.

The best machining conditions for LAM were recorded for experimental runs 5, 2 and 3. Conventional hard turning results of the hardened AISI M2 tool steel are shown in Table 4.

Table 4: Results of conventional hard turn Experiment

EXP. NO.	SCAN SPEED (mm/min)	Resultant Force Hard Turn Fr (N)	Ra (µm)
1	75	68.8	0.2868
2	75	130.1	0.2341
3	75	223.8	0.4205
4	100	267.7	0.3989
5	100	228.7	0.2556
6	100	268.0	0.4646
7	125	348.0	0.5567
8	125	205.0	0.4801
9	125	136.7	0.7330

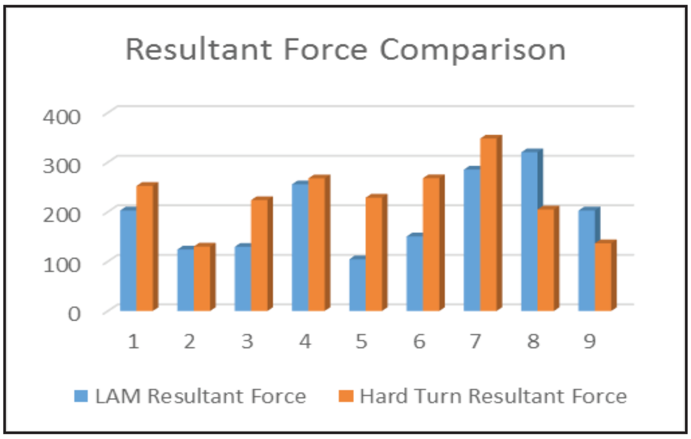

Fig. 2: Resultant Force Comparison

Laser assisted machining was found to have significant effect at lower scan speeds of 75 and 100mm/min. Scan speeds of 125mm/min and above are not recommended as there is not much penetration of the laser beam.

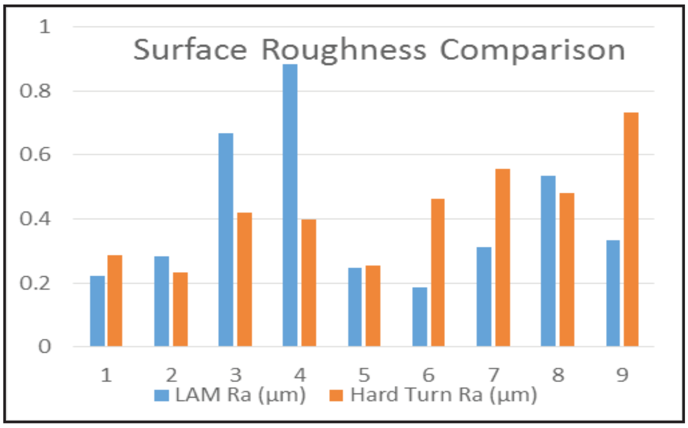

Fig. 3: Surface Roughness Comparison

Fig. 2 shows the resultant force comparison of LAM and conventional hard turning operation.

Fig. 3 shows the surface roughness comparison bar chart of LAM and conventional hard turning. The surface roughness for LAM is comparatively better than the conventional hard turning operation at lower RPM.

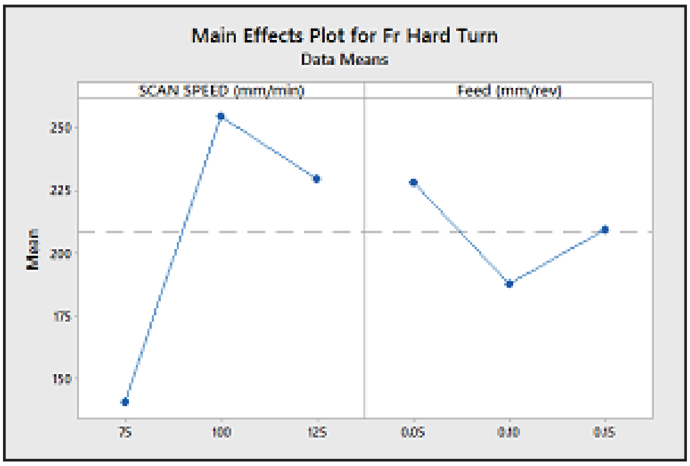

Fig. 4: Main Effects Plot for Resultant Force for Hard Turning

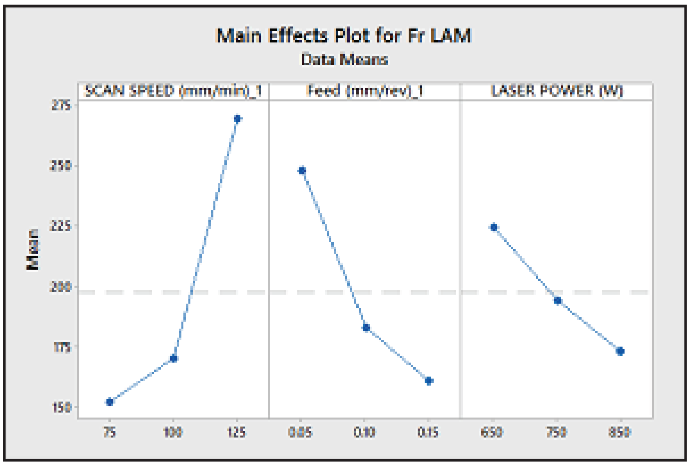

Fig. 5: Main Effects Plot for Resultant Force for LAM

Fig. 4 shows the main effects plot for hard turning. Fig. 5 shows the main effects plot for LAM. Figure 6 shows the contour plot of Resultant force of LAM vs scan speed, laser power. Fig. 7 shows the contour plot of Resultant force of LAM vs scan speed, laser power.

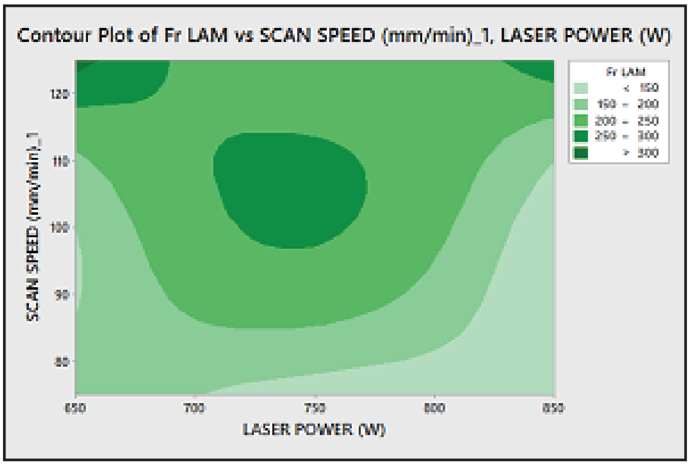

Fig. 6: Contour Plot of Resultant Force of LAM Vs Scan Speed, Laser Power

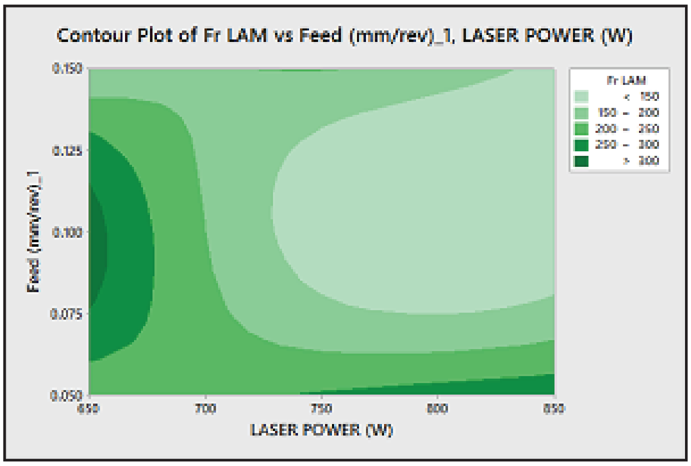

Fig. 7: Contour Plot of Resultant Force of LAM Vs Feed, Laser Power

IV. Conclusion

The results of LAM of AISI M2 tool steel shaft were experimentally analyzed by changing the heating and operating conditions viz. average material removal rate, cutting speed and feed. The hardness of the machined surface dropped by about 1to 2 HRC from the as received state. For both LAM and conventional machining similar hardness profiles were obtained on the machined surface through Rockwell hardness testing.

The surface roughness of LAM was observed to be comparatively better than the conventional hard turning operation. It was observed to improve significantly at a lower scan speed. LAM machining at 850W power resulted in lower cutting force than conventional hard turning to the tune of 5 to 26%.

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