International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Review on Machining of Difficult to Cut Materials

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Abstract: ***Now a day's industries are facing problems for cutting hard metals having hardness greater than50 HRC. Selecting a right process with optimum cost is a challenge for the industries. Lot of factors are affecting the process like tool material, different environments etc.***

Keywords: hot machining, liquid, LAM, UAT

1. Introduction

Now day's industries are facing so many problems in machining difficult to cut materials like alloys molybdenum, titanium, nickel, ceramics. Conventional machining of these materials have problems like low speed, poor surface finish, high tool wear less tool life, low production rate. This set up involves high set up cost and low metal removal rate. To overcome this problem hot machining is one of the most potential techniques developed to machine difficult to cut materials.

Another method to overcome these problems is to application of cutting fluids. Conventional cutting fluids are having many problems because of risk and cost associated with use of flood cutting fluids are hidden or deferred, including: machine tool damage, potential operator health risks, absenteeism, and costs of disposal. Nevertheless, the use of flood coolants is still a common practice in the metal cutting industry. The need for waste management, emphasized by environmental legislation and the associated financial penalties, is driving applied research in this area to formulate cost-effective alternatives. Use of liquid nitrogen is more beneficial as compared with other conventional cutting fluids because it is inert atmospheric gas and contamination free. It is beneficial for metal as well because of non formation of oil film and sterilization is not required.
This article focuses on understanding the role of different environments in the area of machining of hardened steels knowing the current state of art including the inputs from the author's research work. The emphasis of the discussions here is on demonstrating the advantages of different environments in machining of hard to cut materials.

2. Issues in machining of difficult to cut materials

- The force conditions in hard turning are different from those in conventional turning; i.e. the radial force was dominant rather than the tangential force for most of the tool geometries except variable edge hone radius tool. This deviation from the conventional process needs a careful study as the cutting conditions in hard turning are fairly different from conventional material turning i.e. the depth of cut and feed are very low.
- It was observed that as compared to grinding, cylindricity error, like out-of-roundness, was higher for hard turning but still workable, while the parallelism was better in hard turning. But on the entering side, the diameter is smaller due to insufficient conduction of the intensive heat. Flatness error, while being adequate in hard turning, was very high in grinding. Also the axial run out was much higher in grinding. Thus hard turning seemed to be a better option while the ground gear did not fulfill the requirements prescribed in the drawing because of its large flatness error.[1]
- During turning of quenched tempered AISI 1045 and AISI 5140 steels with TiN coated carbide inserts at low speeds, adhesion and micro-chipping are the basic wear mechanisms while at high speeds diffusion and thermal fatigue cracking become severe . By increasing cutting speed, temperature at the contact tool is increased. Thus at elevated temperatures chemical wear becomes a leading wear mechanism and often accelerates weakening of cutting edge resulting in premature tool failure (chipping), namely edge breakage of the cutting tool. Due to this carbide inserts have a limited application to hard turning.[2]
- Hard turning with a sharp cutting tool generates a unique ''hook'' shaped residual stress profile characterized by compressive residual stress at the surface and maximum compressive residual stress in the subsurface but as tool wears out, the nature of the surface residual stresses changes to tensile that reduces fatigue life of component. This is one of the major areas of concern in hard turning.[3]

3. Improvements in Machining process for difficult to cut materials

Following paragraph gives various improvement methods used for machining of difficult to cut materials. These methods namely, hot machining, Ultrasonic assisted turning and cryogenic cooling are discussed here.

3.1 Hot Machining

In order to minimize cutting forces and improve surface finish hot machining is useful for difficult to cut materials. Laser Assisted Machining (LAM) is one of the effective methods for thermal softening of these materials. This process is based on the idea of lowering the cutting forces during machining, by systematically lowering the material yield strength using localized heating. Smoother surface finish due to the lower stresses observed during LAM as compared to conventional machining. The hardness due to machining in machining affected zone of conventional machining is higher than those of LAM [8]Further, tool wear is strongly dependent on the material's removal temperature, and there is an optimum temperature for the longest tool life [9]

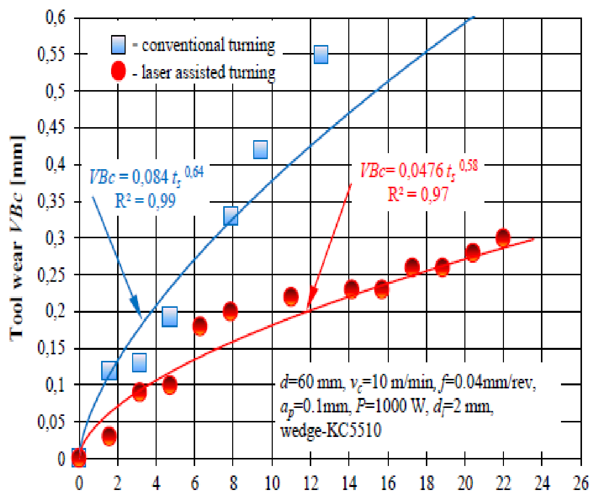

Figure 1: Variation of average tool wear of sintered carbide (KC5510) in function of machining time. [9]

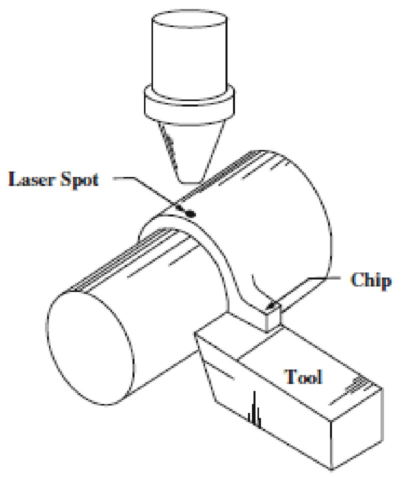

Figure 2: lam setup with laser beam [10]

3.2 Liquid Nitrogen Lubrication (LAM)

As the machining process is based on removal material due to shearing action, there will be large amount of heat generation occurs during cutting. Therefore, it is necessary to minimize these cutting temperatures using improvements in machining environment. Liquid nitrogen cooling is one of the effective methods for cryogenic cooling during machining.

At ambient temperature liquid nitrogen application during cutting operations produces significantly thicker chip. This leads to the higher cooling rate, based on the ability of the chip to remove heat from the tool/chip interface more effectively. The reduced heat dissipation into the tool and work piece is principally responsible for the improved tool life in liquid nitrogen cooling. It is observed that liquid nitrogen acts as an inert barrier beneath the chip produced within the tool and chip interface. Therefore, it causes cryogenic cooling the upper surface of the chip, and restricts coolant access to its underside, steep differential temperature gradients across the chip thickness would be produced. The differential material contraction between the upper and lower surface of the chip appears to enhance the level of chip curl, thereby reducing contact length, and offering the ability for the gas component of the cryogen to enter the capillary network, thereby acting as a lubricant or inert barrier [11]

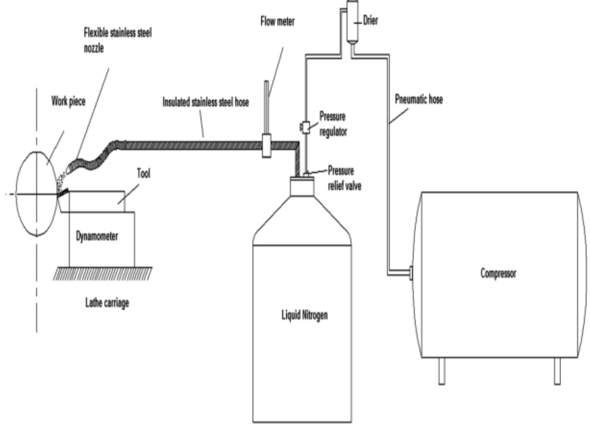

Figure: Mechanism of cryogenic cooling [12]

In the recent past, it was studied by different researchers to understand its benefits for machining of difficult-to-cu materials. Hon and et. al. [13] studied a new economical cryogenic machining approach. This approach uses a minimum amount of LN2 injected through a micro-nozzle formed between the chip breaker and the tool rake and assisted by the secondary nozzle for flank cooling. In this manner, LN2 is not wasted by cooling unnecessary areas and reduces the negative impact of increasing the cutting force and the abrasion of pre-cooling the workpiece material. This cryogenic machining approach yields the best tool life compared with any machining method from current known sources. A.V. Mitrofanov, et.al. [14] studied the effect of lubrication by comparison of simulations with and without friction corresponding to dry and lubricated turning conditions, respectively.

Application of compressed cold nitrogen gas in high-speed end milling of Ti-6Al-4V can provide not only environment friendliness but also great improvement of tool life. Compressed cold nitrogen gas and oil mist is the optimal cooling/lubrication condition to improve the tool life. The tool life under CCNGOM was 2.69 times as much as that under dry cutting condition and 1.93 times as much as that with nitrogen-oil-mist [15] To use minimum amount of liquid nitrogen (LN2) a micro-nozzle is Formed between the chip breaker and the tool rake face, the nozzle lifts the chip and injects focused LN2 into the chip–tool interface at the point of highest temperature. As the nitrogen evaporates, a nitrogen cushion formed by evaporating nitrogen lowers the coefficient of friction between the chip and the tool. An auxiliary mini-nozzle that sprays LN2 onto the flank at the cutting edge further reduces the cutting temperature [16]

3.3 Ultra-sonic Assisted Turning (UAT)

Using this technique high frequency and low amplitude vibrations are given to tool in order to minimize cutting forces and chatter marks on work piece. This study was conducted by various researchers in the past for different materials. However, the use of UAT was not analyzed thoroughly for difficult to cut materials like titanium and nickel based alloys. As given in the literature, UAT method minimizes the cutting force by 70 to 80% at the same time there was improvements in surface finish by 40 to 50% [17]. Fig1. Shows schematic of UAT which includes an ultrasonic transducer with a freq of 20 kHz and amplitude of 10 to 15 µm was given to the cutting tool. By the use of UAT, there is considerable improvement in surface finish. This may be due to vibration given to the tool reduces formation of built up edges, which leads to minimization of surface roughness [18].

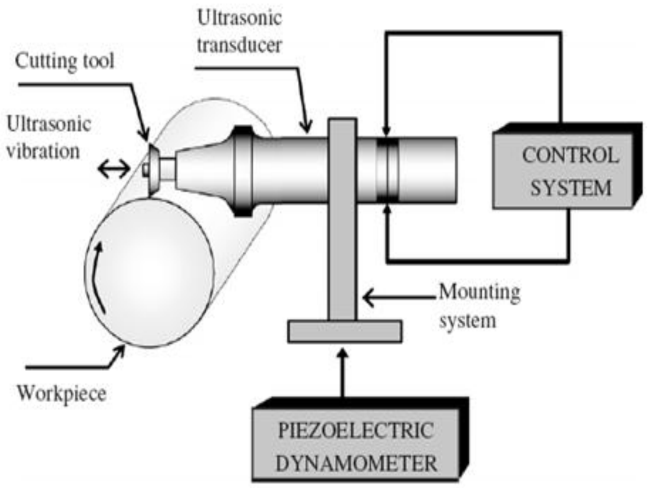

Figure 1: Schematic of UAT Process

4. Conclusion

This paper represented brief review of different environments to overcome difficulty in machining of difficult to cut materials. From above study it is found that all three methods has its own benefits but cryogenic machining is more beneficial.

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