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Dry machining of AA7075 by H-DLC coated carbide end mill

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Abstract

Present investigation evaluates the performance of a hydrogenated diamond like carbon (H-DLC) coating on carbide end mills during machining of an Al-Zn-Mg based alloy i.e. AA7075. Although diamond is known to be the most potential hard coating on carbide tools to deal with the challenges of machining aluminium, DLC coating offers economic solution in dealing with this material at medium cutting speeds. Present study explores the feasibility of using a H-DLC coating, which is eventually softer than non-hydrogenated DLC, in machining this alloy and compares its performance with that of uncoated carbide tools under dry environment. In terms of surface finish and cutting force this H-DLC coated tool substantially outperformed uncoated carbide one in the cutting speed range of 60 to 180 m/min. The coating was able to substantially arrest built up edge (BUE) formation, however, found to be with minor trace of built up layer (BUL).

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Keywords: AA7075 alloy; hydrogenated DLC; BUE; BUL; adhesion; surface roughness; cutting force

1. Introduction

Strict environmental protection laws and cost associated with procurement and disposal of metal working fluids are major motivations behind recently emerged trends towards environmental friendly machining. Dry machining is the most preferred solution to meet the requirement. However, chip-material adhesion to the cutting tool, followed by surface quality deterioration and tool wear, is the major challenges for dry machining of aluminium and aluminium alloys. Adhesion of aluminium on the cutting tool tends to create built up edge (BUE) at lower cutting speed and built up layer (BUL) at higher cutting speed. Adhesion takes place at wider range of temperature. The material

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adhesion is combined effect of work and tool materials, feed rate, rake angle and lubrication (Bao and Stevenson 1976). List et al. (2005) found that chip adhesion is a major wear mechanism of carbide tools under dry machining of aluminium. The reports conclude that BUE occurs at the combination of low temperature and high pressure at tool-chip interface whereas BUL forms at high temperature. The absence of lubrication increases the friction and temperature thereby accelerates the material adhesion (Rivero et al. 2006). Initiation, growth and breaking phases of the adhered material on the cutting tool alter the geometry of the tool continuously. This variation of geometry leads to fluctuation of cutting force and variation in surface generated on the workpiece. Different attempts were made by different research groups to reduce the order of challenges in machining of aluminium, without degrading environment. The approaches focus variation of tool geometry, surface coating, surface texturing, and near dry machining. Nouri et. al. (2003) found that material adhesion on the cutting tool depends significantly on tool geometry and more extended tool life was observed with diamond coated tools than with TiAlN and (Ti,Al)N+WC+C coated tools. Lahres et al. (1997) divided the tool coating material into suitable and non-suitable ones during machining of AlZnMgCu1.5 alloy. Among different coatings, carbon based coatings showed promising results during aluminium machining than other nitride based coatings. Carbon based coatings were found to be free from material adhesion when machining aluminium BS L168; where other nitride, carbide based transition metals and layered MoS₂ coated tools were reported as susceptible to BUE under dry environment (Coldwell et al. 2004). Carbon based coating can be further classified into diamond, DLC, and graphite. DLC is the amorphous carbon coatings containing a combination of sp² and sp³ bonds. Again DLC can be divided into Pure DLC and doped DLC. The pure DLC can be further divided into hydrogenated and non-hydrogenated one. Hydrocarbon based precursors used in the coating process for DLC deposition results in incorporation of hydrogen atoms in the DLC coating. This variety of coatings is hydrogenated one. The performance of the hydrogenated and non-hydrogenated were not similar in all environments. Stallard et al. (2004) concluded that hydrogenated DLC exhibits good tribological performance under dry environment whereas non-hydrogenated performed better in water and oil environments. Bhowmick et al. observed less cutting force and material adhesion with hydrogenated DLC than non-hydrogenated one during dry drilling of 319 Al. The same trend was observed under near dry machining of 319 Al (Bhowmick et al. 2008). In contrary, Jean et al. (2006) observed that both hydrogenated and non-hydrogenated DLC were failed in arresting adhesive wear while machining aluminium alloy, even they performed better in pin on disc tribological test. However the reports are inadequate and contradictory under dry environment. In the present investigation, the ability of the H-DLC coating to arrest the order of adherence; as a more lubricious, less hard carbon based coating, has explored in depth in the medium level speed range.

2. Experimental details

The popular but less studied aerospace alloy AA7075 was selected to evaluate the performance of H-DLC coating. The performance of H-DLC coated carbide end mills was compared with uncoated one in slot milling process. Cutting forces measured in-situ machining and surface roughness measured off-line were used as two major analysing tools to assess the performance of H-DLC coating. The chemical composition of AA7075 is Zn-5.8, Mg-2.4, Cu-1.4, Cr-0.19, Fe-0.17, Si-0.05, Mn- 0.03, Ti-0.08, Al- balance. Carbide end mills with 10 mm diameter and 30° helix angle were used for machining. The hydrogenated DLC coating provided on end mill was commercially provided by Balinit DLC, which provides moderate hardness and less friction coefficient thus provides good barrier against material adhesion. The coating architecture starts from substrate followed by chromium inter layer, CrC transition layer, then C layer. A chromium interlayer was deposited on the carbide end mills to enhance the adhesion between the carbide and DLC. The machining experiments were performed on a Vertical machining center. The experimental conditions are detailed in Table1. Work materials were mounted on the Kistler dynamometer (model: 9257B, Kistler Instruments, Switzerland) as shown in Fig.1 for measuring cutting force. The average surface roughness of the machined surface was measured by Mahrsurf M2 perthometer. The set cut-off length was 0.8 mm. The presence of BUE/BUL was viewed by a stereo microscope and a scanning electron microscope (SEM) coupled with energy dispersive spectroscopy (EDS).



Table 1: Experimental conditions

Machine Tool	Make: Ace Micromatic Pvt Ltd, India; Model: DTC-300, Spindle Power: 5.5 kW
Workpiece Material	AA7075
Cutting Tool	Diameter: 10 mm, No of flutes: 2 Helix angle: 30° Material: Uncoated and DLC coated carbide end mill Cutting Speed: 60, 120, 180 m/min
Machining Parameters	Feed rate : 100, 200, 300 mm/min Depth of Cut : 0.5 mm Width of cut : 10 mm

Fig. 1 Experimental setup: End milling with uncoated and H-DLC coated tool

3. Results and Discussion

3.1. Coating Surface characterization

In general soft or hard coatings can be characterized through hardness, adhesion, morphology etc. Surface properties are very important factor, when it is intended for anti-adhesion. Surface roughness and surface morphology of the coating mainly influence the tribological properties of DLC coatings (Vladimirov A.B et. al 2000). Chip material adhesion mainly depends on the tribological properties of the coatings. Surface profile and morphological study was carried out with the help of perthometer and scanning electron microscope respectively. The R_a value of the uncoated carbide are $0.1 \mu\text{m}$, where the DLC was found to be with R_a of $0.065 \mu\text{m}$. Lower valley depth of DLC coating revealed the presence of DLC in the ground valleys of substrate. The surface morphology of the uncoated carbide and DLC coated end mills were observed through SEM and shown in Fig 2. The grinding marks presents in the uncoated carbide end mills were filled by low frictional carbon based DLC coating. The DLC present in the valleys of ground tool act as a lubricant during machining of soft aluminium materials. The smooth amorphous structured surface was observed on the DLC coatings.

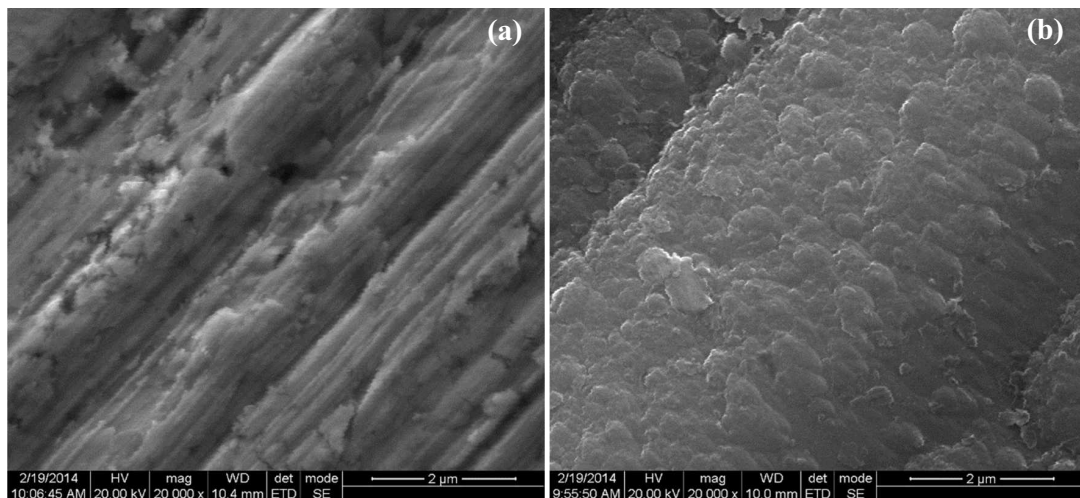


Fig.2. Surface morphology of (a) uncoated carbide and (b) DLC coated carbide end mill

3.2. Surface roughness

The surface roughness of the machined surface depends on cutting parameters, tool geometry tool material and environment. In this study the variation of surface quality of the machined surface was differentiated in terms of surface coating on cutting tool. The machined surface profiles under same machining conditions are compared.

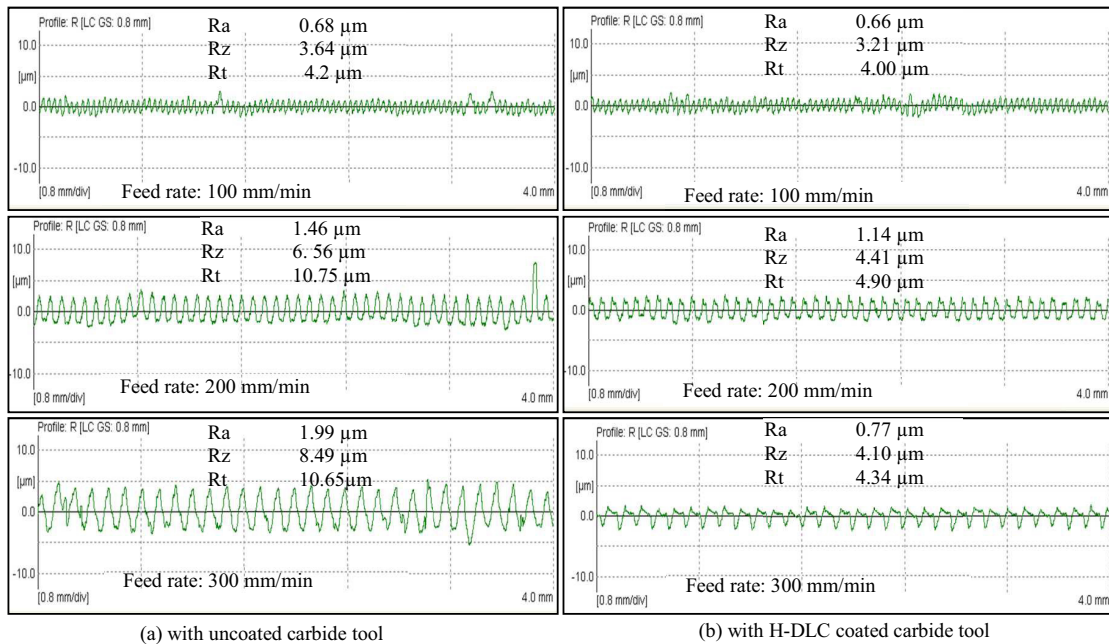


Fig.3 surface profile of machined surface at cutting speed: 60 m/min with different feed rates

The average roughness value of the surface produced by DLC coated tools were less compared to uncoated carbide one. Fig.3 shows the surface profile of the machined surface using uncoated and DLC coated carbides. At 100 mm/min feed rate there was not much difference in surface profile. At higher feed rates occasional increase in profile height was observed on the surface machined by uncoated carbide end mills. On the contrary H-DLC coated tools produced uniform, equal spaced and almost same profile height at each feed intervals. The variation in profile height observed was due to material adhesion on the tool followed by smearing and re-depositing the same on the machined surface.

3.3. Cutting force: Feed and transverse force components

During slot milling operation, the cutting force components were measured online using piezoelectric dynamometer. From the dynamic spectrum of force components in the time domain the more force encountered by the teeth of the cutter was calculated. The same has been plotted for both the components under various speed-feed conditions in Fig. 4(a) and 4(b). It is distinctly evident from these graphical representation that both feed and transverse components of cutting forces increase with increase of cutting feed rate and decrease in cutting velocities. The tooth of the milling cutter encounters higher maximum chip load in either of the mentioned cases, thereby resulting into the escalation of maximum cutting force. Further it can be observed that H-DLC coated end mill cutter outperformed its uncoated counterpart in all cutting conditions. In case of higher feed conditions, the beneficial effect of hydrogenated DLC coating was realized more i.e. the reduction of maximum force level was higher. This could happen possibly due to incapability of uncoated carbide tool to machine this alloy at higher feed because of significantly built of work material on cutting edge.

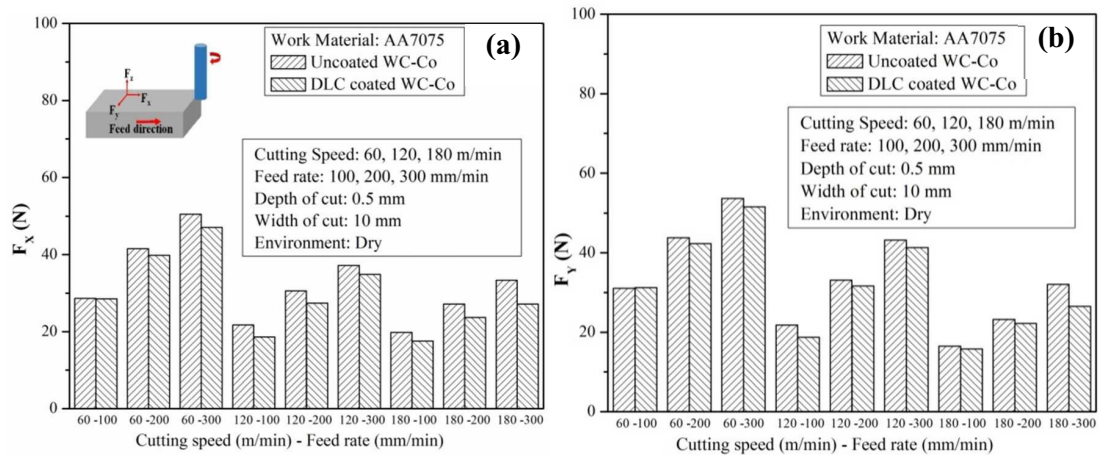


Fig. 4. Variation of (a) F_x and (b) F_y force component during machining of AA7075 by uncoated and DLC coated carbide end mills

3.4. Observation on BUE and BUL

For the purpose of comparing the severity of BUE, the initial machining test was carried out with AA1050. Figure 5 shows the SEM and EDS of the uncoated and H-DLC coated end mills after machining AA1050 under same cutting conditions. The severe built up edge were observed with uncoated carbide whereas small trace of BUE was found on the DLC coated end mills. The material build up on the uncoated carbide and H-DLC coated end mills after machining AA7075 was very less (Fig.6). The tendency of adherence was reduced possibly due to alloying elements like zinc, magnesium, copper, as present in the AA7075.

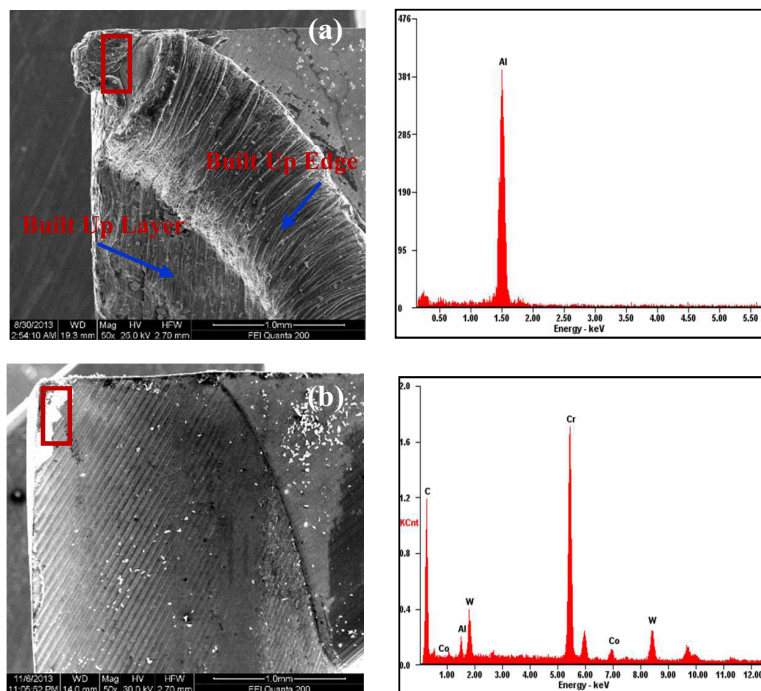


Fig.5. SEM images and EDS Spectra of uncoated carbide end mills after machining AA1050 using (a) uncoated and (b) DLC coated carbide end mills (cutting speed =60m/min; feed rate=200mm/min; depth of cut: 0.5 mm; width of cut: 10mm)

An uncoated carbide tool showed higher percentage of aluminium on the EDS analysis than H-DLC coated one. The combination of BUE and BUL were observed on the rake face of the uncoated tool. BUL covered the large region of the rake face. The small quantity of aluminium was observed on the DLC coated tools by EDS analysis. At severe cutting conditions, traces of aluminium layer were observed on H-DLC coated tools. The minor traces of BUL was found possibly because of adhesion of aluminium on the porous micro-pockets, created by the escaped H-atoms during high speed-high feed machining condition.

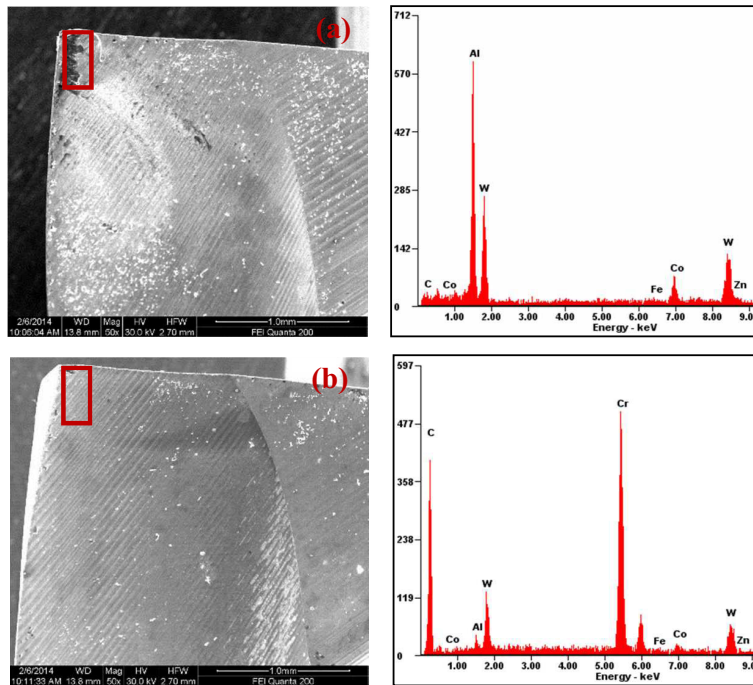


Fig.6. SEM images and EDS Spectra of uncoated carbide end mills after machining AA7075 using (a) uncoated and (b) DLC coated carbide end mills (cutting speed =60m/min; feed rate=200mm/min; depth of cut: 0.5 mm; width of cut: 10mm)

4. Conclusions

- H-DLC coating on end mill cutter with Cr-interlayer was found to appear with amorphous like structure and could offer a smoother finish on rake face of end mill than that of uncoated one.
- H-DLC coated tool performed the machining operation steadily in the range of 60 to 180 m/min cutting speeds at all feed conditions unlike the uncoated carbide one. The H-DLC coating appears to offer an economic (with respect to diamond coated tools) solution to machining aluminium at medium speed range.
- H-DLC coating although found to arrest BUE formation was detected with minor trace of BUL.
- AA 7075 alloy was found to cause less-severe aluminium adhesion as compared to pure aluminium, possibly due to presence of alloying elements like zinc and copper.

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