IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 3 Ver. III (May. - Jun. 2015), PP 07-14
www.iosrjournals.org

Elimination of White Layer formation during Hard Turning of AISI D3 Steel to improve Fatigue life

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Abstract: *Hard turning (above 45HRC) has become an economically, environmentally, and technically competitive process when compared with grinding. Machining induced surface integrity can be characterized by surface roughness, micro-hardness, microstructure, residual stresses, etc. During hard turning, formation of white layer on turned surface of component. The white layer has an increased hardness when compared with the bulk material and is often associated with tensile residual stresses. Although the thickness of the white layer is usually several micrometers, the presence of it causes great component's performance, such as fatigue life. Hard turning is very real due to the existence of the white layer, which is presumed detrimental to component life. A component free of a white layer can have a life six times that of a white layer component. As the white layer increases in thickness, the fatigue life decreases [1]. There are some factors that need to be considered for white layer formation during hard turning. The mechanism of rapid heating and quenching resulting in transformation products, Surface reaction with the environment Such as nitriding, carburizing and oxide ploughing, Plastic flow producing a homogeneous structure or one with a very fine grain structure [2]. Experiments were performed machining of hardened D3 Steel under dry and gas using chamfered CBN tool inserts. Experimental techniques were used in the analyzing scanning electron microscopy (SEM), Field emission scanning electron microscopy (FESEM) were utilized for the surface topography characterization, chemical characterization (phase study) was carried out by means of Energy dispersive X – ray spectroscopy (EDAX) techniques, and Surface textures produced by means of non contact techniques. The results show the benefits and the future potential of gas cooling for surface integrity and improve the fatigue life of component enhancement and to achieve improved product's functional performance in hard turning by way of eliminating the White layer formations concerns in the machining industry and academia because the effect of the white layer on a machining surface is considerable one.*

Keywords: *Fatigue life, Hard turning, Hardened steel, Shielding gas, White layer formation,*

I. Introduction

Hard turning is performed on materials with hardness within the 45–68 Rockwell range using a variety of tipped or solid cutting inserts, preferably CBN. Although grinding is known to produce good surface finish at relatively high feed rates, hard turning can produce as good as better surface finish at significantly higher material removal rate. Although the process is performed within small depths of cut and feed rates, estimates of Reduced machining time is as high as 60% for conventional hard turning. Studies have shown that using the right combination of insert nose radii, feed rate or the new insert technology, hard turning can produce better surface finish than grinding. Multiple hard turning operations may be performed in a single setup rather than multiple grinding setups. This also Contributes to high accuracy achieved by hard turning. During hard turning, the white layer was formed on machining surface. The white layer is a very thin outer layer of material that is harder than the underlying material. The white layer formation is a phase transformation rich in retained austenite [3].

II. Literature Review

As per the literature survey, studied the causes of white layer by following factors:

a) The mechanism of plastic flow producing a homogeneous structure or one with a very fine grain structure.
b) The mechanism of rapid heating and quenching resulting in transformation products.
c) The mechanism of surface reaction with the environment such as nitriding, carburizing and oxide ploughing[3].

The white layer thickness depends upon the other factors are cutting parameter, Tool wear VB and BUE. Thus, it was generally believed that to reduce or avoid the white layer formation and, consequently to improve the surface integrity, it is necessary to decrease the temperature, protect the tool and contact surface from atmosphere at the time of turning. This is mainly done with the application of Shield gas. Also, the convective cooling effect of cutting fluids on this affected layer has not yet been clarified. Showed that Shield gas spray cooling of cutting tool and tool-work contact would limit the thickness or eliminating white layer.

Therefore, the objective of this paper is to investigate the effects of Shield gas coolant on both white layer formation and surface roughness evolution during hard machining of AISI D3 steel. Experiments were performed under dry and Shield gas coolant conditions using chamfered CBN tool inserts at effective cutting speeds. Several experimental techniques were used in order to analyze the machined surface and subsurface. In particular, Scanning electron microscopes (SEM) and Field emission scanning electron microscopes (FESEM) were utilized for the surface topography characterization. The chemical characterization was carried out by means of Energy dispersive X – ray spectroscopy (EDAX) technique and non conduct test was used to determine roughness of machined surface (Ra and Rz) and phase changes induced by machining under dry and Shield gas cooling conditions.

III. Experiments

Experiments were conducted on a stiff high speed CNC lathe (JOBBER XL) with manual impinging Shield gas (Argon 80% with 20% CO_2) at 3 bar pressure delivery system provided (Fig. 1). In particular, orthogonal cutting operation was performed by using CBN tools containing about 100% CBN, grade CB7015 by Sandvik Coromant. TNGA 160408 S01030 chamfered inserts. (Providing nose radius 1mm and 0.8 mm for with and without shield gas process respectively). The Shield gas coolant was applied by a gas welding nozzle to the area of interest indicated in Fig 1 to provide the cooling effect at the primary, secondary and tertiary shear zones. Circular rod of hardened AISI D3 steel (outer diameter = 34 mm) were prepared, machined and heat-treated.

Fig 1 Hard turning of D3 steel using Argon with CO_2 gas impinging as coolant

Heat treatments were performed in order to through-harden the Circular rod to 61±1HRC. Then, rod were turned used by CBN insert at varying cutting speeds (110m/min, 160 m/min and 210 m/min) at a fixed feed rate of 0.15 mm/rev and depth of cut 0.1mm for all dry and gas cooling conditions. In such conditions surface temperature was measured (150ºC,175ºC.195ºC dry and gas coolant of 33ºC,96ºC,107ºC respectively)on the utilization of IR sensor. After machining, samples of 5 mm depth were sectioned in the shape of crescent by wire-EDM for microstructure analysis and micro hardness measurements. Then, the samples were grinding EDM cutting side with cutting fluid use as coolant to reduce to 2.5mm thickness to mount for FESEM and etched for about 10 s using 4% Nital solution to observe white layer using a Field emission scanning electron microscope (FESEM). By using Energy dispersive X – ray spectroscopy (EDAX) in order to conduct a qualitative elemental analysis of the machined surface for two samples
With dry and gas coolant conditions.

IV. Results And Discussion

White layer and surface micro hardness

From the literature survey (more thickness WL formation in between cutting speed 100 to 300m/ min) produced by varying the cutting speed and the cooling condition. Fig 2 (b) shows the experimental white layer thickness at cutting speed of 100m/min,400 m/min,700 m/min and Fig 2 (a) indicate Flank wear increase with increase in cutting speed[3].

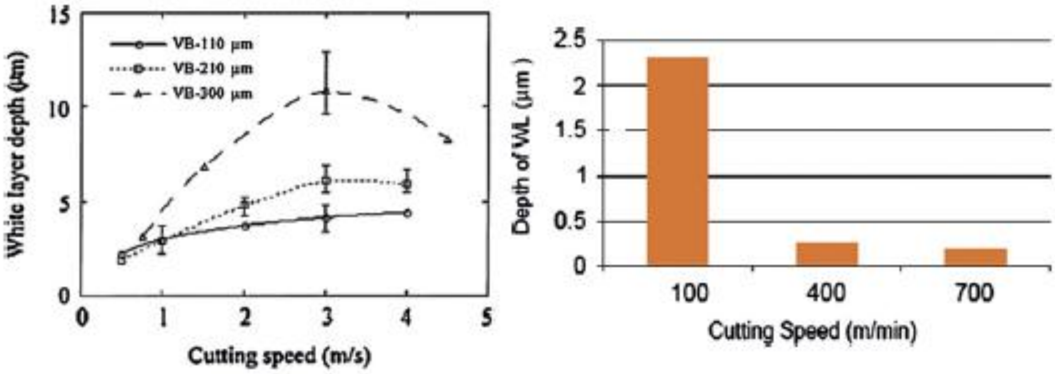


Fig 2 a) Effect of cutting speed on white layer depth and tool wear V_B.
b) Effect of cutting speed on white layer depth.

Fig 3(a) shows the experimental white layer thickness produced by varying the cutting speed and the cooling condition. In particular, the white layer eliminates, when shield gas (Argon with CO_2) used for more than 2 μm during dry cutting. Furthermore, the white layer decreases with the increasing cutting speed. However, the study of concept is that white layer eliminates obtained using shield gas cooling. The average of grinding surface hardness value 54.16 HRC , average of non grinding surface hardness value 60 HRC , average of shield gas surface hardness value 47 HRC and average of dry turned surface hardness value 52.33HRC shown in Fig 3(b).

White layers were observed with hardness more than that of the bulk material. There was a depletion of iron and chromium while increase in carbon and oxygen content in the white layer. While tool wear increased with the increase in cutting speed, the white layer depth and hardness actually reduced. This may be due to the fact that at high speeds the temperature of the work piece material reduces while that of the chip increases. Reduction in the temperature of machined surface may be due to faster chip removal and insufficient contact time. Due to this lesser heat is conducted into work piece while most of it is carried away by the chip. This study was also observed. While analyzing white layer during the hard turning of AISI 52100 steel with CBN insert , TEM results suggested that white layers produced at low-to-moderate cutting speeds were largely due to grain refinement induced by severe plastic deformation, whereas the white layer formation at high cutting speeds was mainly due to thermally-driven phase transformation [3]

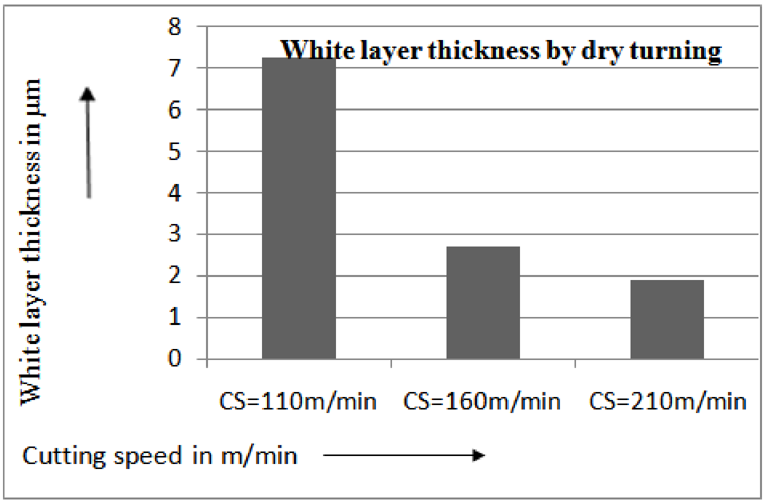


Fig 3 (a) Experimental white layer thickness

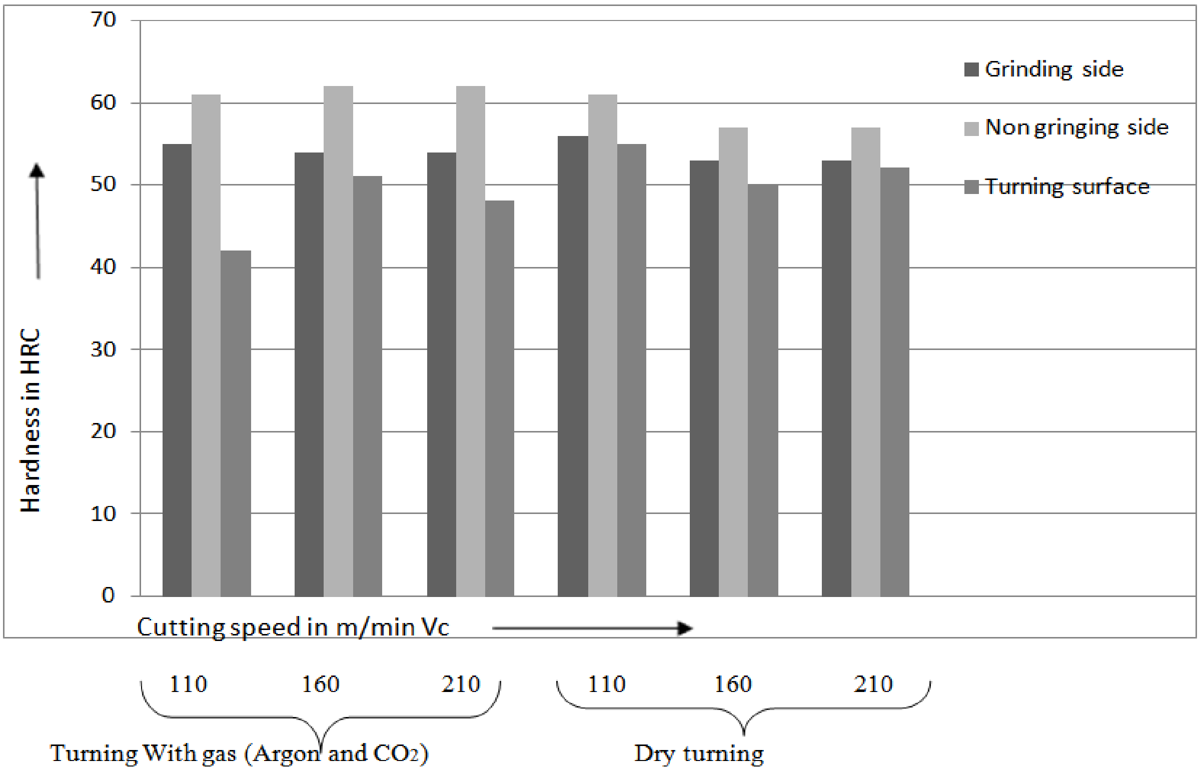
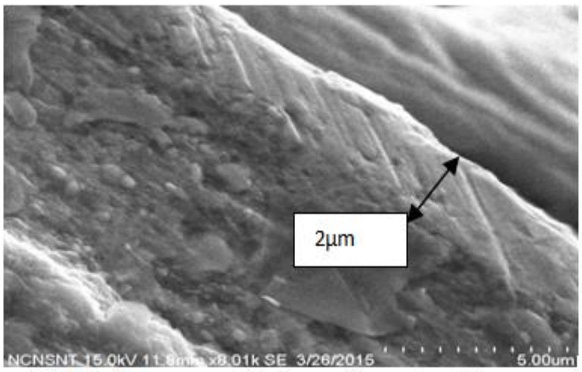
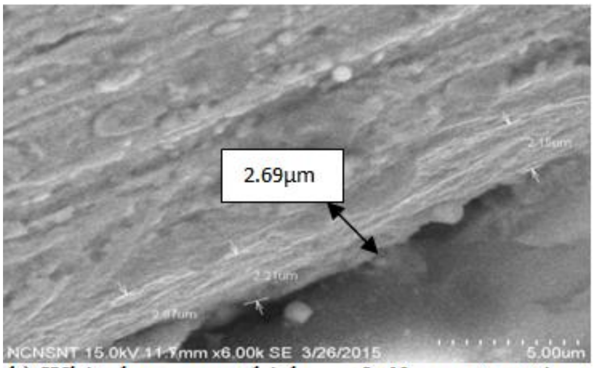


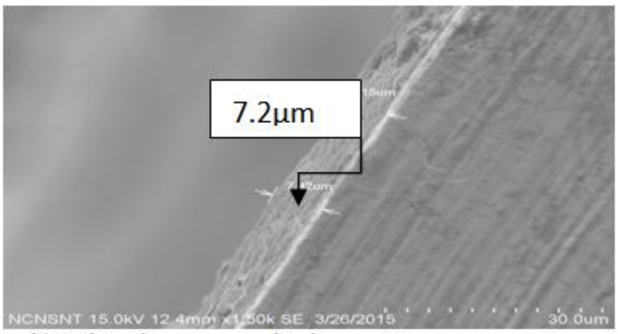
Fig 3 (b) surface hardness modification at varying cutting speeds and the cooling methods. Cutting speed (m/min)/ constant Feed rate (0.15mm/rev)/Hardness (HRC)



a) White layer avg. thickness 2µm at cutting speed 210 m/min

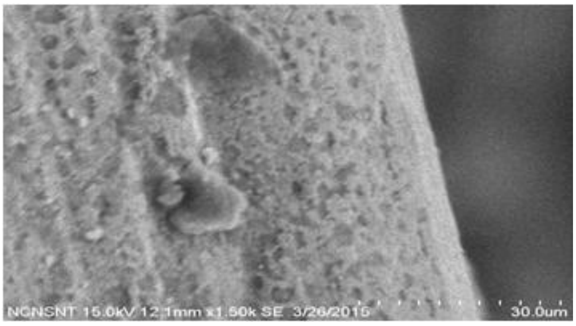


b) White layer avg. thickness 2.69 µm at cutting Speed 160 m/min

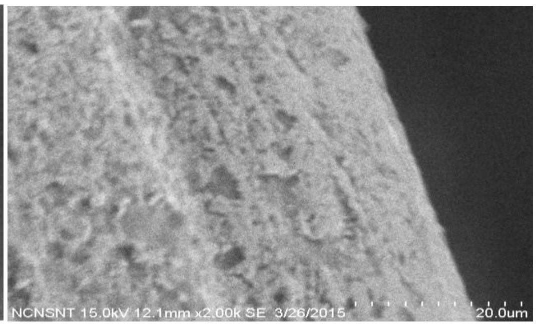


b) White layer avg. thickness 7.2 µm at cutting speed 110 m/min

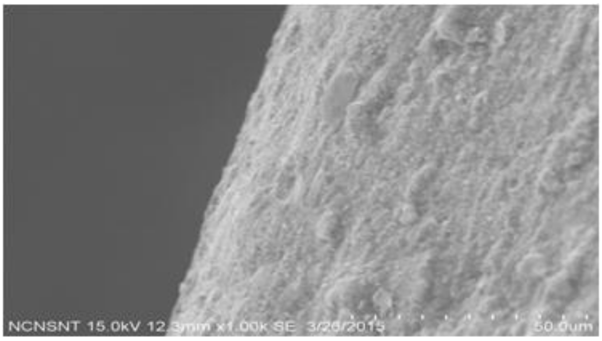
Fig 4(a) FESEM images of dry turning



a) At cutting speed 110 m/min



b) At cutting speed 160 m/min



c) At cutting speed 210 m/min

Fig 4(b) FESEM images of turning with mixed gas(Argon & CO_2 gas)

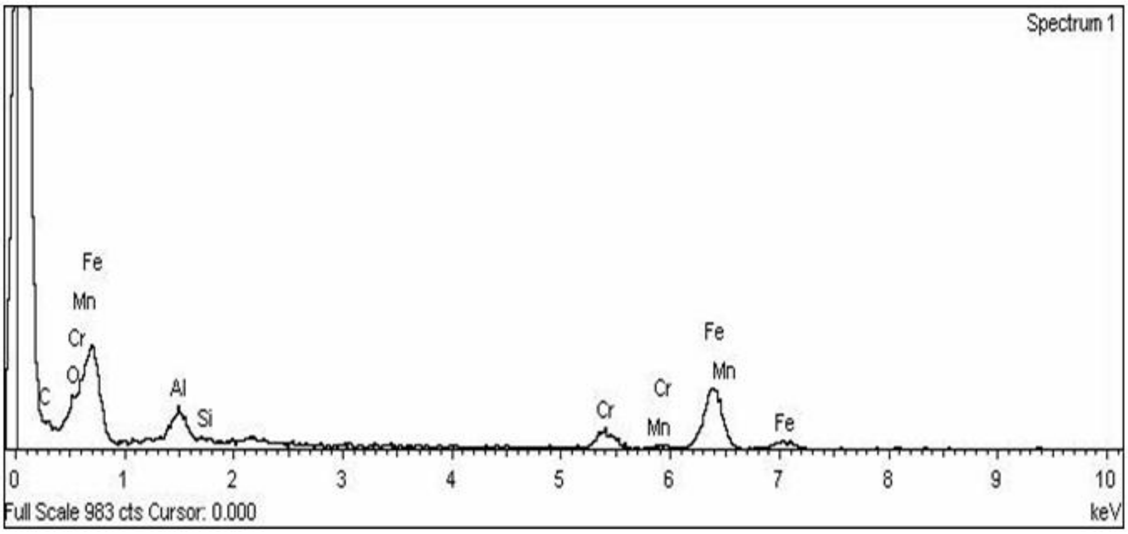


Fig 5 a) At cutting speed 210 m/min (Dry turning)

Fig 5 EDAX (Energy dispersive X – ray spectroscopy) phase analysis on specimens machined in dry conditions (a) and those machined with shield gas cooling (b) vs. dry machined samples: 61 HRC, CBN chamfered tool of 1mm and 0.8 mm nose radius respectively, feed rate 0.15 mm/rev.

Table 5 (a) Chemical composition of specimen (Dry turning EDAX)

S.No	Element	Weight	Atomic %
1.	C k	4.73	13.77
2.	O k	12.87	28.16
3	Si k	1.04	1.30
4	Mn k	1.44	0.92
5	Cr k	9.95	6.70
6	Fe k	69.97	43.83
Total		100	

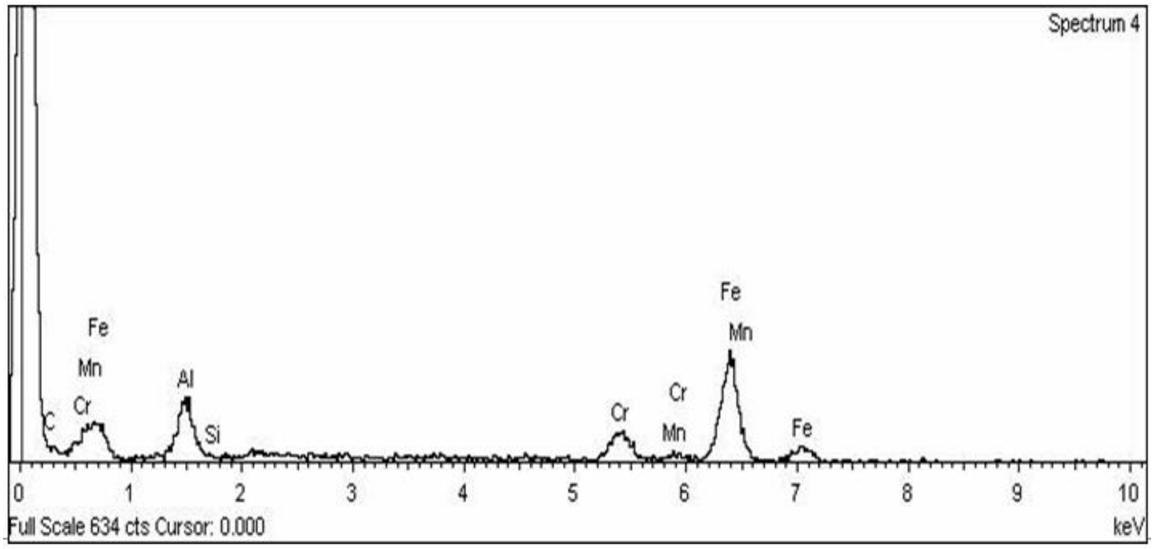


Fig 5 b)At cutting speed 210 m/min (with Argon and CO_2 gas)

Table 5(b) Chemical composition of specimen (EDAX)

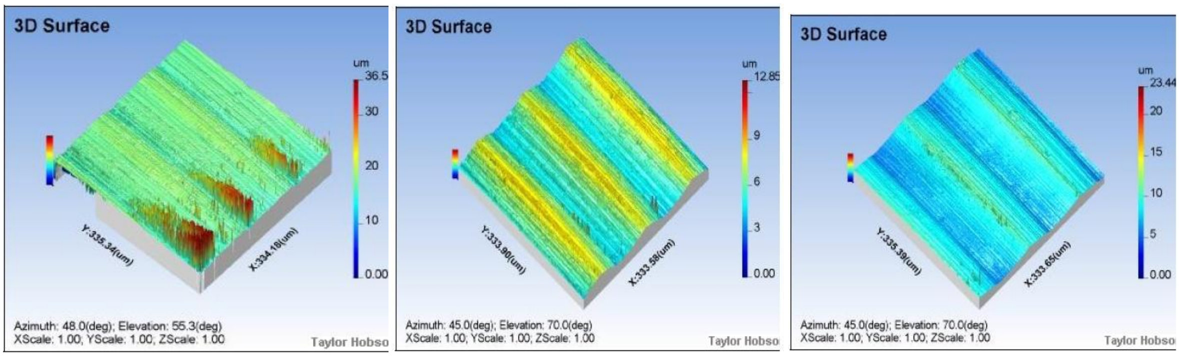
S.no	Element	Weight	Atomic %
1.	C k	17.16	39.52
2.	O k	2.30	3.97
3	Si k	0.04	0.04
4	Mn k	0.16	0.08
5	Cr k	18.48	9.23
6	Fe k	61.27	30.65
Total		100	

V. Analysis Of Chemical Composition

Any chemical compositional changes during transformation are analyzed by the EDX and EDAX etc. but EDAX is very commonly employed method for analyzing chemical compositional changes by FESEM images. In general main elemental compositional changes are taken into consideration. For instance, there will be a significant amount of depletion (reduction) of iron and chromium but there will be a substantial increase in carbon as well as oxygen .The changes will be expressed in weight percentage, since the compositional variation are taken in weight percentage. Whenever there is a white layer formation, iron and chromium so evidence. Hence there is increase in carbon and oxygen also obvious.

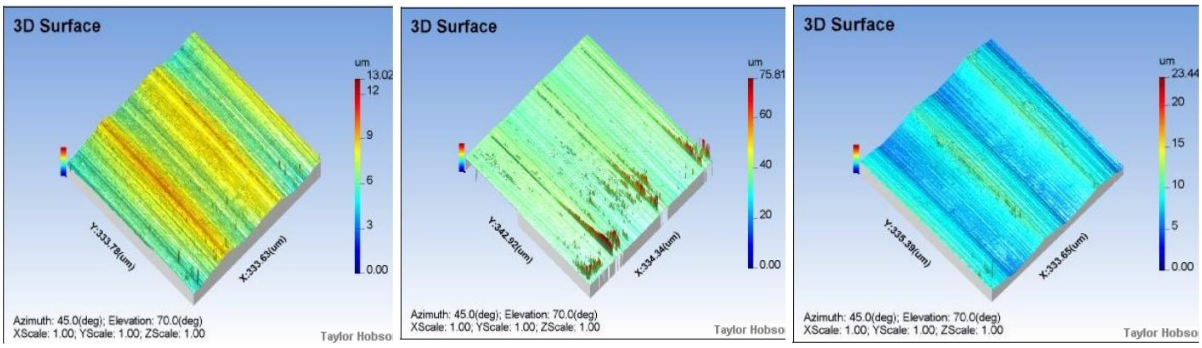
VI. Characterization Of Surface Topography

Surface topographies generated by HT (with and without gas) operations were recorded using a Non contact test. The determination of 3D roughness parameters and 3D visualization of machined surfaces were performed .HT dry turning performed by CBN TNGA 160408 S01030 chamfered insert with nose radius 0.8mm and gas cooling used with radius 0.1mm. By grinding operation Al_2O_3 Ceramic wheel (350 x 25 x 127 32A) and water soluble emulsion as a coolant. Machining conditions for cutting and abrasive operations are performed with 5 pass and achieved surface roughness of Ra = 0.27µm [4]



a) Ra = 0.107 µm b) Ra = 0.103 µm c) Ra = 0.0516 µm

Fig 6(Turning with gas): a) Vc =110m/min, b) Vc =160m/min, c) Vc =210m/min



a) **Ra** = 0.0568 µm b) **Ra** = 0.0716 µm c) **Ra** = 0.0516 µm

Fig 6 (Dry turning): a) Vc =110m/min, b) Vc =160m/min c) Vc =210m/min

Table 6. Comparison of Surface roughness of grinding operation Al_2O_3 Ceramic wheel (350 x 25 x 127 32A) by 5 pass Ra = 0.27µm and turning (with and without gas)

S.No	Parameter Dc=0.1mm,Feed rate = 0.15mm/rev	With gas	Without gas
1.	Vc = 110 m/min	0.107 µm	0.0568 µm
2.	Vc = 160 m/min	0.103 µm	0.0716 µm
3.	Vc = 210 m/min	0.0516 µm	0.0516 µm

From the Surface roughness table we observed the surface finishing of HT was better than grinding operation. The time consumption for finishing is more than HT. Surface finishing in HT is depend upon the tool wear , nose radius and cooling gas is better than liquid cutting fluid. Because the gas pressure is to avoid BUE.

VII. Conclusion

The following facts were observed after reviewing the works discussed above:

- Surface roughness after hard turning is as good as grinding operation. Surface finishing in HT which depends on tool wear, nose radius and cooling gas was better than liquid cutting fluid. It is because of the minimization of BUE (Built up edge) and V_B (flank wear) by the use of gas pressure.
- Material removal rate by HT operation was also higher compared to the grinding operation.
- Hardness of dry turning Surface (57HRC) was higher than the surface turning in gas coolant condition (54HRC) because oxygen reaction and carbon content was less.
- The shield gas (Argon with CO_2) was used as coolant which reduces the cutting temperature and also protect the machining surface from atmosphere. It reduces or minimizes the phase transformation.
- The use of Argon 80% with CO_2 20% gas, which completely eliminated the white layer. It is due to the higher Argon gas (0.0017837 gm/cm³) and CO_2 (0.001977 gm/cm³).They are higher than the atmospheric air density(0.001292 gm/cm³).
- Surface roughness of HT is lower than grinding operation.
- This work used Argon with CO_2 as shield gas of HT of D3 steel to eliminate white layer. In future investigating may be done to use these gases for the HT of D2 steel.

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