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NUMERICAL ANALYSIS OF HARD MACHINING OF AISI 52100 STEEL USING UNCOATED AND COATED AL_2O_3-TICN BASED MIXED CERAMIC INSERTS

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ABSTRACT
Machining hardened materials whose hardness is in the range of 45HRC to 65HRC is a difficult task and cubic boron nitride (CBN) or Polly-crystalline diamond (PCD) tools are normally used for such purpose. Earlier researchers showed that hard coated carbide and CBN tools showed a remarkable improvement in cutting performance of the tools. In recent past alumina and titanium carbo-nitride based ceramic inserts (Al_2O_3-TiCN) are being successfully used for machining hard materials that are much cheaper than CBN and PCD tools. Deposition of hard coatings on this mixed ceramic insert may further enhance the performance of the tool. In this context, present work is focused on studying the effect AlCrN, AlTiN and TiAlN coating on Al_2O_3-TiCN inserts while turning AISI 52100 hardened steel at 62 HRC hardness. A finite element model was developed with the help of DEFORM 3D software for turning hardened AISI 52100 steel using both uncoated and coated Al_2O_3-TiCN inserts. The cutting tool is taken as rigid whereas the workpiece is considered as plastic. Johnson-Cook model was used for characterizing the flow stress of the workpiece material. Based on the earlier research a coating thickness of 3 µm was assumed for the selected hard coatings. The cutting speed, feed and depth of cut were kept constant at 110 m/min, 0.05 mm/rev and 0.5 mm respectively. The tool holder was specified as per the specifications of PSBNR2020K12. The effect of various coatings on the machining forces, interface temperature, and maximum tool temperature was studied. A considerable reduction in machining forces, interface temperature and maximum tool temperature is observed in the finite element analysis carried out for different coated inserts with AlCrN coating showing the maximum reduction. The reduction of these output responses in coated inserts would eventually result in a decrease of thermal and mechanical wear of the cutting tool that would result in enhancement of the life of the tool. This result is expected to be useful for researchers as well as tool engineers related to hard machining.

Keywords:
ceramic insert, DEFORM, FEM, turning

INTRODUCTION
Hard turning is a finishing or semi-finishing operation aimed at obtaining very low values of surface roughness while machining hard materials whose hardness varies in the range of 45-70 HRC [1]. In recent past hard turning has proved to be a major alternative to grinding process increasing material removal rate and thus, resulting in reduction of production cost and time. [2] Many researchers investigated performance of PCBN, CBN and ceramic tools while machining hard materials owing to their higher wear resistance and hot hardness [2,3]. Recently alumina based composite ceramic tools have been successfully employed in hard machining due to their economical nature [4,5].
Deposition of hard coatings on the cutting tools proved very helpful in improving the machining performance of the cutting tools [6,7]. Aslantas et al. [3] investigated tool life, tool wear and surface finish obtained while machining AISI 52100 hardened steel with Al_2O_3-TiCN mixed ceramic insert. The results revealed that coated insert produced better surface finish and tool life as compared to uncoated insert. Aslan et al. [8] determined optimum cutting parameters for minimum flank wear and surface roughness while machining hardened AISI 4140 steel using Al_2O_3-TiCN mixed ceramic insert. Das et al. [9] performed turning experiments on hardened AISI 4140 steel using coated and uncoated Al_2O_3-TiCN mixed ceramic insert. The experiments and optimization results revealed that flank wear increases with increase in cutting speed and depth of cut while feed rate had minimum effect. It was also found that coated tool gave better results in regard of surface finish and also serrated chips were formed at higher feed rate resulting in poor surface finish.

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Sobiyi et al. [2] compared wear behavior and surface finish obtained while turning AISI 440B stainless steel with CBN and mixed ceramic inserts. It was observed that in ceramic tools wear took place mainly due to abrasion whereas in CBN tools wear took place due to abrasion as well as adhesion. Endrino et al. [10] studied the effect of AlCrN and AlTiN coatings on carbide tool and found that coated tool outperformed uncoated tool in terms of tool life and surface finish. Mechanical properties and chemical behavior of the coatings were also investigated during the study. Yang et al. [11] studied microstructure and determined mechanical properties of Al_2O_3-TiCN based mixed ceramic material. Brito et al. [12] examined the heat influence on diamond cutting tools with TiN and Al_2O_3 coatings. Martan and Benes [13] examined and studied the behavior of thermal properties of various coating at high temperatures. Shrot et al. [14] studied various Johnson-Cook model parameters given for AISI 52100 hardened steel and performs an inverse investigation to verify these parameters at high cutting speeds where identical adiabatic stress-strain curves were obtained and concluded that agreement between simulation and experimental results don't indicate the proper selection of parameters. Attanasio et al. [15] studied residual stresses on the surface while cutting AISI 1045 using Lagrangian and Eulerian solvers. Umbrello et al. [16] proposed a hardness-based flow stress and fracture models based on Johnson-Cook flow stress model and Brozzo's fracture criteria. Grzesik [17] studied influence of thin single and multi-layer hard coatings on frictional behavior while machining AISI 1045 steel and AISI 304 stainless steel. Nohava et al. [18] discussed wear behavior of AlCrN and AlTiN coatings at high temperatures. Hu et al. [19] studied wear of ultrafine-grained and common ceramic tool and observed that ultrafine-grained ceramic tool outperformed common ceramic tool in terms of wear rate and wear depth. Yen et al. [20] used finite element analysis to predict tool wear during orthogonal cutting operation. In the present approach tool geometry was modified to study the wear effect on the tool.

From the extensive literature review carried out, it is evident that investigations on effect of hard coatings on mixed ceramic is limited. Also, finite element analysis study for coated cutting tools has not been carried out extensively. Thus, the present work focuses on numerically investigating the effect of AlTiN, AlCrN and TiAlN hard coatings on Al_2O_3-TiCN mixed ceramic insert substrate while hard turning of AISI 52100 steel at 62 HRC hardness.

FINITE ELEMENT MODELLING

Fig. 1.1 shows the finite element modelling (FEM) setup that is carried out with the help of DEFORM 3D software for both coated and uncoated insert at constant cutting speed of 110 m/min, depth of cut of 0.5 mm and feed of 0.05 mm/rev. The tool is modelled as rigid with 150000 mesh elements whereas the workpiece is modelled as plastic material with 80000 mesh elements. Flow stress for the workpiece is modelled according to the Johnson-Cook parameters considered by Kim et al. [21]. A coating thickness of 3 µm has been considered for all coated inserts [22]. Tool holder was created as per specifications of PSBNR2020K12. Thermally dependent material properties for the workpiece have been considered in the work owing to high temperatures generated during the hard machining process [23]. The tool material properties has been adopted from the work carried out by Yang et al. [24] whereas, the material properties for different coatings has been adopted from the manufacturers products and services guide [25] (see Table 1).

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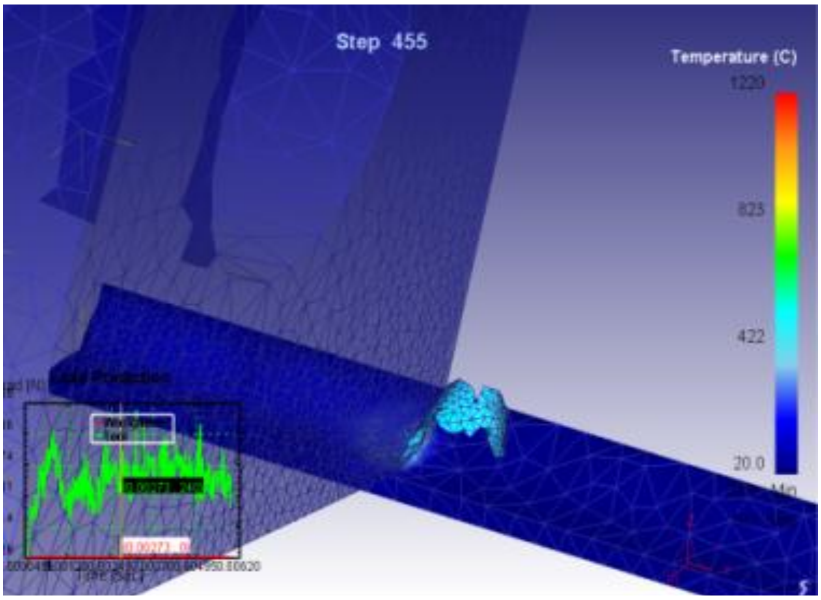

Fig. 1.1: Finite element modelling setup

Table 1.1: Properties of coating material

Property	AlCrN	AlTiN	TiAlN
Young's Modulus (GPa)	600	570	450
Poisson ratio	0.3	0.205	0.25
Coating color	Bright grey	Grey	Violet grey
Friction coefficient against steel	0.35	0.35	0.3
Maximum service temperature (^{0}C)	1100	1000	900
Micro-hardness (HV 0.05)	3200	3000	3300
Emissivity	0.45	0.45	0.5

RESULTS AND DISCUSSION

FEM analysis has been used to study the effect of AlCrN, AlTiN and TiAlN coatings on Al_2O_3-TiCN ceramic inserts. The results that are obtained from numerical study are as follows.\

Effect on Machining Forces

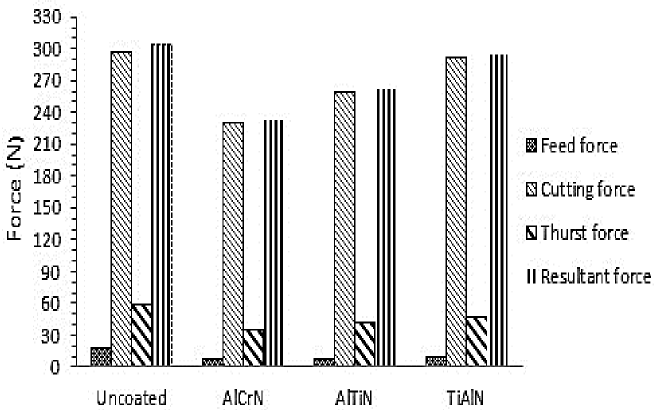

Fig. 1.2: Machining forces for coated and uncoated Al_2O_3-TiCN based mixed ceramic insert

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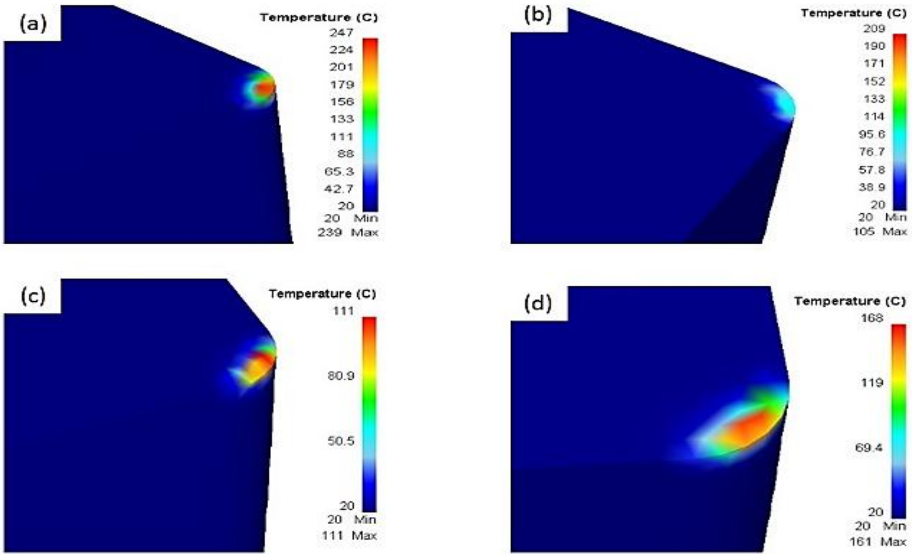

Fig. 1.3: Tool temperature (a) uncoated (b) AlCrN coated (c) AlTiN coated (d) TiAlN coated.

Deposition of hard coatings resulted in significant reduction of machining forces. Fig. 1.2 shows the comparison of machining forces for uncoated and uncoated tools. It is evident from the graph that AlCrN coated tool showed maximum reduction of machining forces as compared to uncoated cutting tool. Application of coatings resulted in a maximum reduction of 22.5% of cutting force, 62.3% of feed force, 32% of thrust force and 13.5% of resultant force. This, reduction of machining forces suggests a lower coefficient of friction for coated tools.

Effect on Tool Temperature

Application of coatings resulted in decrease in tool temperature. This reduction of temperature may be due to the collective effect of lower thermal conductivity offered by the coating material and also due to the reduction of machining forces for coated tools. Fig.1.3 depicts temperature distribution in coated and uncoated tools. It is evident that maximum reduction in tool temperature is recorded for AlCrN coated tool owing to the lower magnitude of machining forces generated. Fig. 1.4 shows a comparison of tool temperatures for coated and uncoated Al_2O_3-TiCN cutting tools.

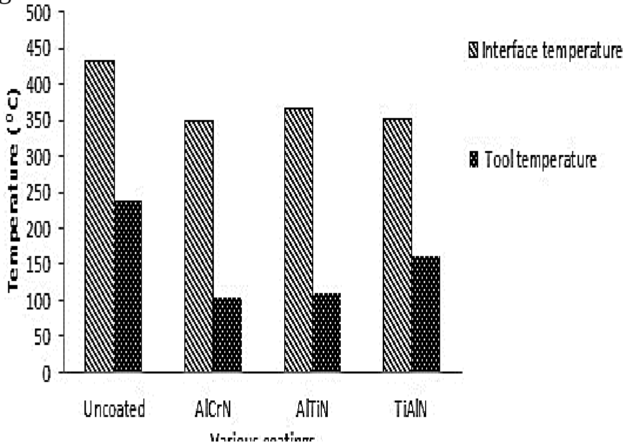

Fig. 1.4: Interface temperature and maximum tool temperature for coated and uncoated Al_2O_3-TiCN based mixed ceramic inserts.

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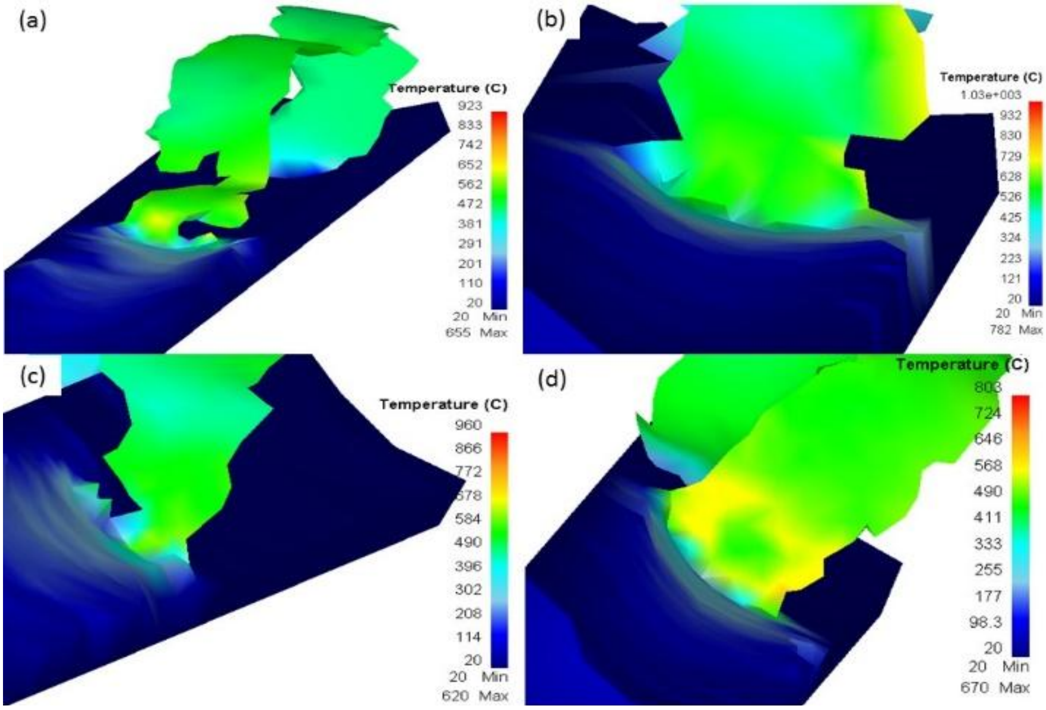

Fig. 1.5: Interface temperature (a) uncoated (b) AlCrN coated (c) AlTiN coated (d) TiAlN coated

Effect on Interface Temperature
A reduction of temperature is also observed at the cutting zone (tool-workpiece interface) while machining with coated cutting tools (see Fig. 1.5). AlCrN coated tool resulted in maximum reduction of temperature whereas, maximum interface temperature was observed for uncoated tool. This reduction of temperature at the cutting zone is a favorable condition for reduction of tool wear.It is evident from the numerical results that AlCrN coted tools performed better than ATiN and TiAlN in terms of reduction in machining forces, tool temperature and cutting zone temperature. These observations provide a beneficial base for researchers in the field of hard machining. The numerical results can be validated experimentally and also, study of coated tools under varying cutting conditions and parameters has a good scope of future study.

CONCLUSION

The conclusions from the present 3D finite element numerical analysis are summarized as follows:
- Deposition of hard coatings on Al_2O_3-TiCN resulted in reduction of machining forces.
- Significant reduction of tool temperature was observed while machining with coated tools.
- Interface temperature also decreased marginally for coated tools.

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