EVALUATION OF DYNAMIC PARAMETERS IN TURNING OF Al7075/CNT COMPOSITE

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ABSTRACT

In this paper, turning experiments are conducted on Al 7075/CNT (Aluminum Metal Matrix composite) sample at different combination of speed, feed and depth of cut according to Taguchi design of experiments, developed based on parameters and their levels. The machining responses cutting force, thrust force and temperatures are recorded. Finally, dynamic parameters such as flow stress, strain, strain rate and temperature at secondary shear zone of work material are evaluated using constitutive model (Oxley's model) based experimental data.This work is more useful for development of metal cutting software to conduct wide simulations to analyze the cutting process and design of cutting tools.

Keywords: Dynamic parameters, Oxley's model, JC model, DOE.

1. INTRODUCTION

Metal cutting is an important phenomenon in the manufacturing industry since the major cost of a product comes from processing the materials. The last century has witnessed a revolution in methods and techniques adopted in machining a variety of materials. The factors critical to ease of machining are material behavior at the microscopic and macroscopic level. The variation in the metallurgical properties of materials necessitates a thorough assessment of their machining characteristics for optimizing the cutting conditions and the tooling and production systems

To assess and validate the performance of the JC constitutive equation in modelling the deformation behavior of Al 2024-T351 alloy. Orthogonal machining experiments were conducted at nine different cutting conditions by varying cutting speed and feed. An FE model was constructed in Deform 2D and the flow stress data calculated from the JC model parameters, based on Oxley machining model was input into the FE code. The FE results for cutting force, chip thickness and temperature were compared with those of the experiments. The effective stress, strain and strain rate were analyzed for the various cutting conditions [1-5].

To determine the flow stress behaviour of the work material within the range of strain, strain rate and temperature encountered during chip formation process by means of inverse modelling of orthogonal cutting operations. This approach was based on the concept of Design of Experiments (DOEs) and Response Surface Methodology (RSM). Initially, an extension of Oxley's machining theory incorporating the Johnson-Cook material model was integrated with RSM to accomplish a fast assessment of the material parameters. Having provided the material parameters by Oxley's machining theory, the optimum set of friction coefficients were determined through evaluation of the Finite Element (FE) simulation results [6-10]

The dynamic mechanical behavior of machining Ti6Al4V beyond the range of strains, strain rates, and temperatures in conventional materials testing and predicted the flow stress characteristics of strain hardening and thermal softening with the JC model [11-14].

Ozel (1998) et al.improved the methodology for determining flow stress developed by Kumar by using Zorev's (1963) friction model at the work- tool interface and modified the flow stress data till FEM results matched experiments[15-17].

Lesuer and Cockroft, M.G. performed experimental investigations of material models for Ti6Al4V titanium and 2024-T3 aluminum. The ability of the JC material model to represent the deformation and failure responses using DYNA 3D FE code was evaluated and a new set of material parameters were defined for the strength component of the JC model for Ti6Al4V and 2024-T3 aluminium materials[18-19].

Jasper's and Dautzenberg [20] utilized the Split Hopkinson's test to calculate the flow stress data in metal cutting and evaluated the predictive abilities of the JC and ZA flow stress models. It was concluded that the JC model was good in predicting the flow stress for AA 6082 (T6) aluminium alloy while the ZA model was good for the predictions with AISI 1045 steel material.

The literature suggests that the least square approximation technique that fit to SHPB data is the most frequently used methodology to identify and optimize the flow stress model parameters. Flow stress is dependent on the nature of experiments and is sensitive to the material model parameters. The flow stress data for machining has to accurately map the deforming material in machining conditions for which it is necessary to identify flow stress as a function of the machining process itself or methods to optimize existing parameters to fit the deformation processes through FEM.Though many approaches have been used to fine tune and optimize the material parameters, most of the models require superior mathematical skills and are time consuming.

After carrying out review on literature it is found that little work has been done on use of Oxley's model in turning of AMMNC related to evaluation of its dynamic parameters. To address this aspect, the present work is done for evaluation of dynamic parameters in turning of AMMNC.

2. ORTHOGONAL CUTTING EXPERIMENTS

2.1 Work material and tool

An AMMNC sample is used as work material which was prepared using stir casting process by reinforcing CNT of 1% by weight into Al 7075 matrix. A multi coated carbide insert mounted on a tool holder was used to cut the work material under dry conditions. The cutting speed was kept constant and the feed rate was increased for different cycles. Table 3 shows the experimental cutting conditions. Table 4 shows the specification of the cutting tool.

2.2 Experimentation

Table 1 shows the specification of the Lathe used for the orthogonal cutting process. Figure 3and 4 shows the photographs of the experimental setup. The instruments like temperature gun and Lathe tool dynamometers are used for measuring machining responses.

Table 1: Lathe specifications

Name	NAGMATI-175 lathe
Centre height (mm)	175
Spindle speeds (rpm)	54 – 1200
Swing over cross slide(mm)	215
Swing over bed(mm)	350
Cross slide travel(mm)	215
Compound slide travel(mm)	118
Tail stock quill travel (mm)	140
Longitudinal feed range(mm)	0.045 – 0.716

Fig. 1: Lathe tool dynamometer

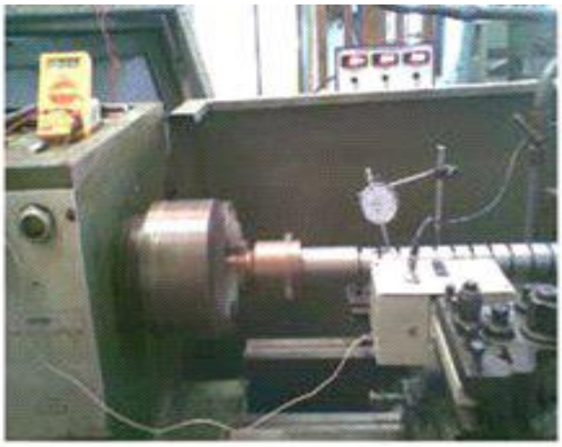

Fig. 2: Turning experiment

Turning experiments were carried out on aluminum metal matrix nano composite (AMMNC) at a cutting speed of 280, 450,710, 1120 rpm and feed rates of 0.2,0.25,0.3 and 0.36 mm/rev. according to Taguchi orthogonal array L16 (Table.), which is developed based on the cutting conditions employed for turning of AMMNC material, are cutting speed, feed and depth of cut at four different levels is shown in Table.2.

Table 2 Input process parameters for machining of AMMNC

Parameters	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Speed (rpm)	280	450	710	1120
Feed (mm)	0.2	0.4	0.6	0.8
Depth of cut(mm	0.2	0.25	0.32	0.36

Table 3 Experimental conditions for machining AMMNC

Work material	AMMNC
Work dimensions (mm x mm)	250 x 100 (length x outer diameter)
Cutting speed (m/min)	102
Feed rates (mm/rev)	0.2, 0.25, 0.3&0.36
Environment	Dry

Table 4 Cutting tool specifications for machining of AMMNC

Tool holder	PCLNR H12
Insert type	CNMG 120408
Rake angle (°)	-5
Clearance angle (°)	+5
Insert material	WC – CO coated with Ti CN, Al_2O_3,Ti N

Table: 5 Orthogonal array with machining data

S. N O	Input parameters			Output parameters		
	Speed (rpm)	Depth of cut (mm)	Feed (mm)	Cutting force(N)	Thrust force(N)	Temperature (^{o}C)
1	280	0.2	0.2	39.24	9.81	36.8
2	280	0.4	25	88.29	19.62	37.2
3	280	0.6	0.32	137.34	29.43	39.2
4	280	0.8	0.36	176.58	39.24	39.6
5	450	0.2	0.2	39.24	9.81	36.8
6	450	0.4	25	68.67	9.81	38.8
7	450	0.6	0.32	78.48	19.62	37
8	450	0.8	0.36	137.34	19.62	36.5
9	710	0.2	0.2	49.05	9.81	36.8
10	710	0.4	25	78.48	9.81	37.4
11	710	0.6	0.32	137.34	19.62	39
12	710	0.8	0.36	186.39	39.24	39.8
13	1120	0.2	0.2	39.24	9.81	36.7
14	1120	0.4	25	88.29	19.62	36.8
15	1120	0.6	0.32	127.53	19.62	37
16	1120	0.8	0.36	166.77	29.43	38.3

3. Oxley's model and relationship between dynamic parameters

The constitutive model of Oxley's modelis used in this work for evaluation of dynamic parameters at secondary shear zone shown in Fig.3

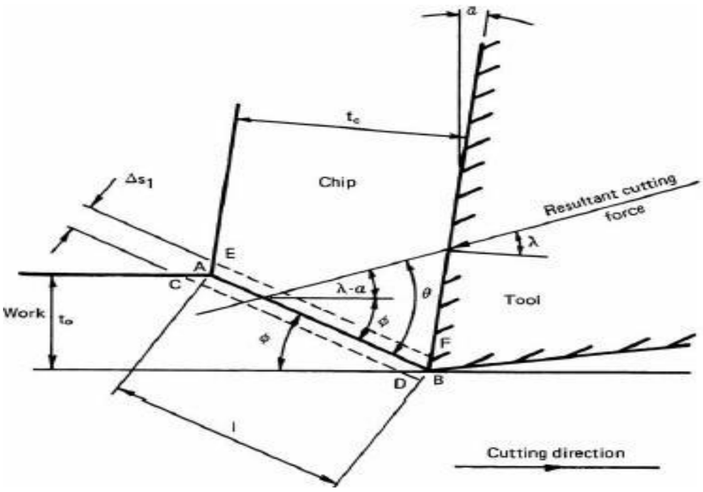

Figure 3: Parallel sided shear zone model

Oxley's model is used to predict the dynamic parameters such as stain, strain rate, and temperature. The description of this model is given in the following

Effective shear strain rate along shear plane AB,

$\gamma AB = C0(VS / lAB)$ Eq(1)

C0 = 5.9

Strain rate constant proposed by Oxley $l_{AB} = t_u / \sin(\Phi)$ Eq (1)

Shear velocity $V_S = \{v \cos\alpha / [\cos(\Phi - \alpha)]\}$ Eq (2)

γ_{AB} is the Effective shear strain rate along shear plane AB

$\gamma_{AB} = \{ \cos\alpha / [2\sin\Phi \cos(\Phi - \alpha)] \}$ Eq (3)

Shear angle $\Phi = \tan^{-1}\{ [(t_u/t_c)\cos\alpha] / [1 - (t_u/t_c)\sin\alpha] \}$ Eq (4)

k_{AB} is the Shear flow stress along shear plane AB

$k_{AB} = [F_S \sin\Phi / (t_u w)]$ Eq (5)

Shear force $F_S = [F_C\cos\Phi - F_T\sin\Phi]$ Eq (6)

$T_{AB} = T_0 + \{[(1-\beta) F_S\cos\alpha] / [\rho S t_u w\cos(\Phi - \alpha)]\}$ Eq (7)

R_T =Non-dimensional thermal number

$R_T = [\rho S V t_u / K]$ Eq (8)

Flow stress $\sigma_{AB} = \sqrt{3}k_{AB}$ Eq (9)

1

Strain along the Shear plane AB, $\varepsilon_{AB} = (\gamma_{AB} / \sqrt{3})$ Eq (10)

Strain rate along the Shear plane AB $\acute{\varepsilon}_{AB} = (\cdot\gamma_{AB} / \sqrt{3})$ Eq (11)

The orthogonal cutting test values of 1% AMMNC Table (7) are feeded as input to Oxley's model and obtained results are given in Table.7

4. Johnson -Cook model

The Johnson-Cook constitutive model Eq. (12), gives the flow stress as the product of strain, strain rate and temperature, which have been calculated from Oxley's model. The J-C constants (Table.6) for the AMMNC were taken from author own work.

$$\sigma = [A+B\varepsilon^{n}]\ [1+C\ln(\acute{\varepsilon}/\varepsilon_0)]\ \{1- [(T - T_0)/(Tm - T_0)]^{m}\} \quad \text{Eq (12)}$$

Table. 6 J-C constants for AMMNC

JC Constants	A[MPa]	B[MPa]	C	n	M	Tm[K]
AMMNC	535	579	0.018	0.74	1.64	900

Johnson cook model is used for determining flow stress based on Oxley's model values and JC constants. obtained results are given in Table.7

Table 7: Results obtained from Oxley's model

S.NO	Strain ε_{AB}	Strain rate $\acute{\varepsilon}_{AB}$ (s^{-1})	Temperature T_{AB}(^{0}C)	Flow stress (N/mm^2)
1	0.90	1080.38	42.67	1365.95
2	0.62	1157.17	43.19	1409.63
3	0.77	644.71	40.78	884.35
4	1.36	697.56	41.10	980.84
5	0.93	699.92	39.52	752.07
6	0.97	500.90	39.09	1893.06
7	1.50	632.90	37.51	530.32
8	0.84	779.83	38.74	696.63
9	0.45	1269.14	37.62	696.34
10	0.82	1922.31	39.04	721.43
11	0.60	1918.99	40.02	862.37
12	0.64	1310.18	38.57	742.96
13	1.65	925.35	38.49	467.09
14	0.96	1073.68	37.33	407.44
15	0.59	1490.56	40.37	844.30
16	1.06	1450.27	39.02	630.41

5. RESULTS

5.1 FLOW STRESS and TEMPERATURE

The values of flow stress and cutting temperatureobtained from Oxley's model are noted for work sample as in Table. 8 and also graph is drawn between them as in Fig. 4.

Table:8 Flow stress and Temperature

S.No	Temperature T_{AB}(^{0}C)	Flowstress N/mm^2
1	42.67	1365.95
2	43.19	1209.63
3	40.78	884.35
4	41.10	980.84
5	39.52	752.07
6	39.09	893.06
7	37.51	530.32

1

8	38.74	696.63
9	37.62	696.34
10	39.04	721.43
11	40.02	862.37
12	38.57	742.96
13	38.49	467.09
14	37.33	407.44
15	40.37	844.30
16	39.02	630.41

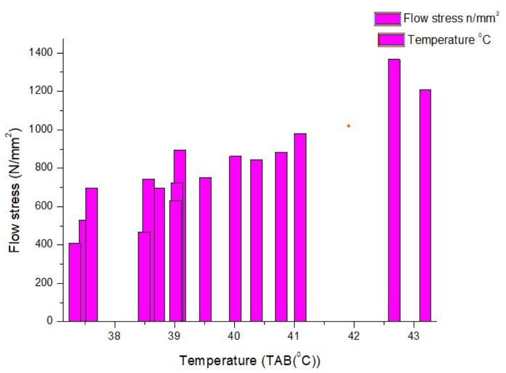

Fig. 4: **Flow stress Vs Temperature**

From thefigures,flowstressincreases,asthetemperature increases, Because of deformation of metal. The temperature generated;the amount of heat produce is increases.

5.2 FLOW STRESS AND STRAIN

The flow stress and strain values from Oxley's model are noted table 9, to study the dependence between them.

Table 9: Flow Stress and Strain

Test	Flow Stress (N/mm2)	Strain (ε_{AB})
1	1365.95	0.90
2	1409.63	0.62
3	884.35	0.77
4	980.84	1.36
5	752.07	0.93
6	1893.06	0.97
7	530.32	1.50
8	696.63	0.84
9	696.34	0.45
10	721.43	0.82
11	862.37	0.60
12	742.96	0.64
13	467.09	1.65
14	407.44	0.96
15	844.30	0.59
16	630.41	1.06

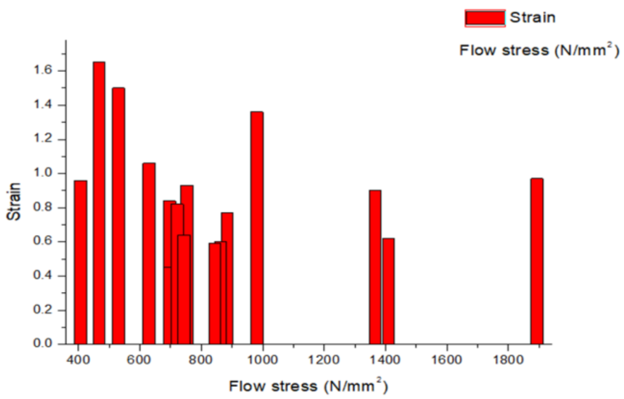

Fig. 5: Flow stress Vs Strain

From the figure,as the strain increases, the flow stress increases gradually because of strain hardening of material.

5.3 FLOW STRESS AND STRAIN RATE

The flow stress and strain rate values from Oxley's model are noted table 10, to study the dependence between them

Table 10: Flow Stress and Strain rate of sample

Test	Flow Stress (N/mm2)	Strain rate έAB (s^{-1})
1	1365.95	1080.38
2	1409.63	1157.17
3	884.35	644.71
4	980.84	697.56
5	752.07	699.92
6	1893.06	500.90
7	530.32	632.90
8	696.63	779.83
9	696.34	1269.14
10	721.43	1922.31
11	862.37	1918.99
12	742.96	1310.18
13	467.09	925.35
14	407.44	1073.68
15	844.30	1490.56
16	630.41	1450.27

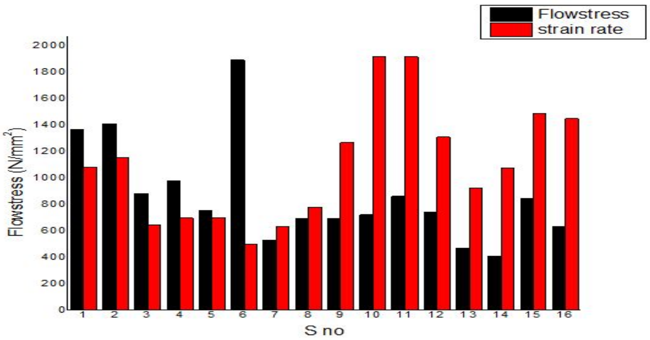

Fig. 6: Flow stress Vs Strain for sample

From the figure,as the strain rate increases, the flow stress increases gradually because of strain hardening of material.

6. CONCLUSIONS

In this work, the dynamic parameters of Al 7075/CNT material such as Flow stress, Strain, Strain rate and Temperature at secondary shear zone are evaluated successfully using constitutive model developed by Oxley for different cutting conditions.This work is more useful for development of metal cutting software to conduct wide simulations to analyze the cutting process and design of cutting tools. Further this work will be extended for other materials and cutting conditions.

CRediT authorship contribution statement

M. Madduleti: preparation of work material, turning operation, numerical modeling, investigation and validation, original draft preparation.**P. Venkataramaiah:** Conceptualization, Data curation, Formal analysis, Project administration, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Data availability

he raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

Ethical approval

No animals have been used in any experiments.

Consent to participate

No humans have been used in any experiments.

Consent to publish

The author confirms that the work described has not been published before (except in the form of an abstract or as part of a published lecture, review, or thesis); that it is not under consideration for publication elsewhere; that its publication has been approved by all co-authors, if any; and that its publication has been approved (tacitly or explicitly) by the responsible authorities at the institution where the work is carried out.

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