IOP Conf. Series: Materials Science and Engineering **390** (2018) 012113 doi:10.1088/1757-899X/390/1/012113

Analysis of Chip Reduction Coefficient in Turning of Ti-6Al-4V ELI

Anurag, R kumar*, K K Joshi and R K Das

School of Mechanical Engineering, Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar-751024, India

E-mail: ramanujkumar22@gmail.com

Abstract: Titanium alloys are generally used in aerospace industries due to its ability to retain its high strength at elevated temperatures. Present paper deals with Taguchi optimization approach applied to optimize process parameter in turning of Ti-6Al-4V ELI (grade 23) titanium alloy workpiece with coated carbide tool under dry condition. The trails carried out by employing L9 orthogonal array. Linear regression modelling was adopted to develop a model for prediction of experimental results. The predicated results lay proximal to the experimental value. Main effects plot and ANOVA are used to analyse the effect of input variables namely speed (v), feed (f) and depth of cut (d) on chip reduction coefficient. The optimal parameter setting obtained for chip reduction coefficient is *d3-f1-v1* i.e (d = 0.4 mm; f = 0.04 mm/rev; v = 46 m/min).

1. Introduction

In recent decades titanium alloys have proven to be a novel material for industrial applications. Titanium alloy mostly used in aerospace industries and biomedical implants due to its ability to hold its high strength at elevated temperature, excessive resistance to corrosion, low density, and low thermal conductivity. But machining of this alloy recessed high cutting speed but it generates high amount heat at the cutting point, which alters the tool life, roughness of the machined surface. To analysis, the machinability aspects of titanium alloy during turning process are essential to study the chip morphology. Chip formation depends on the material mechanical and thermal properties. At high cutting speed, continuous chip converts into serrated chip formation by the thermal effect which affected the cutting force and wears in the cutting tool. Gao and Zhang [1] investigated the effect of the cutting condition on serration found in the chip during turning process and found that when the rake angle is a more than the decrease in the size of sawtooth but the increment in the total number of sawtooth. Hua and Shivpuri [2] analysed the segmentation of chip while the turning of titanium alloy. Stress state is changed at the cutting zone is change when the increments in the cutting speed cause in the shifting in the fracture mechanism from cutting insert edge to the rest surface of the chip. This changing in the fracture is main causes of converting of discontinuous chips into the serrated chip. Sutter and List [3] probed the changing in the mechanism of chip formation during the turning of the Ti-6Al-4v alloy at elevated rotational speed. It was observed that the rotational speed is a predominant aspect for formatting the formation of the chip also the angle of shearing and length of crack affected the chip formation. Dargusch et al. [4] deliberated the influence of the wear of cutting insert on chip formation during turning of Ti-6Al-4V alloy under dry cooling condition. When the tool worn increased then the friction between the cutting insert and chip also increased which causes of increased in twining deformation and chip formation through both tensile and compressive. Bai et al. [5] researched the formation chip throughout orthogonal cutting of Ti-6Al-4V alloy and observed that the contact length of tool-chip, cutting forces, coefficient of friction and shear strain at the shear region is reduced with in the decrease in the speed and chip-segmentation rise with an increment in rotational speed with a reduction in the feed. Wu and To [6] investigated the effect of the serrated formation of the chip during machining of titanium alloy using Johnson-Cook (JC) model and FEM model. Found that especially rake angle affected the serrated chip formation its decrease with large rake angle. Sun et al. [7] researched the machining of

IOP Conf. Series: Materials Science and Engineering **390** (2018) 012113 doi:10.1088/1757-899X/390/1/012113

Ti-6Al-4V alloy using Cryogenic compressed air cooling condition found that at a low speed more friction between tool and workpiece causes a reduction in the thickness of chip and at low speed, with low feed, the chip segment convert irregular to the regular segment. Aramcharoen [8] studied the influence of tool wear and chip formation in turning of titanium alloy using cryogenic cooling condition. When friction is reduced between tool and chip the produced chip shape is the helical and small radius of curvature. Sahoo and Sahoo [9] examined the effect of the multilayer coated cutting tool during hard turning and optimized the optimal cutting condition for the roughness of the machined workpiece surface using RSM and grey relation approach. Kumar and Kulkarni [10] investigated the surface finish throughout the turning of titanium alloy. Taguchi method reduced the total number of the experiment. Found that the cutting edge radius is specially affected the surface finish. Sulaiman et al. [11] predicted the impact of cutting variables on the machining performance during machining of Ti-6Al-4V ELI using RSM technique. Found out the optimization condition for tool life and surface roughness at elevated cutting speed with low feed or depth of cut. Ramana [12] investigated the optimal process parameters for the roughness of the machined surface using ANOVA technique during machining of the Ti-6Al-4V alloy under various lubrication conditions. Observed that axial feed rate is the major factor that influences the finish of turned surface in all cooling condition. Gupta et al. [13] examined the turning of titanium alloy (grade-2) utilizing RSM approach in MQL cooling condition. Predicted the optimized cutting condition for low surface roughness, low cutting force and tool worn machining at low cutting speed with low feed with high side cutting edge angle. Bandaoalli et al. [14] investigated the surface roughness during the milling of titanium alloy (grade-5) using ANN, GMDH and MRA technique. Result showed that the depth of cut and axial feed rate is predominant factor for the imprecision of machined surface but when the feed and depth of cut are constant than roughness declines with increment in the rotational speed. Kumar et al. [15] found that the turning speed and radial depth of cut were the predominant factor for the chip reduction coefficient also found that high CRC value measured while using uncoated carbide tool as compare to coated carbide tool. It was observed from the literature analysis that the most of the research papers deal with Taguchi methodology for optimization of the separate performance characters.

2. Experimental Methods

Ti-6Al-4V ELI (grade-23) titanium alloy workpiece having length 100 mm and diameter 35 mm used as the machined material. The hardness of Ti-6Al-4V ELI alloy is (35±1) at normal surrounding temperature. A WIDIA made coated carbide (CNMG 120408) cutting insert manipulated for the machining. HMT NH22 high-speed lathe machine used for present tuning process. All the experiment performed under dry cooling environment.

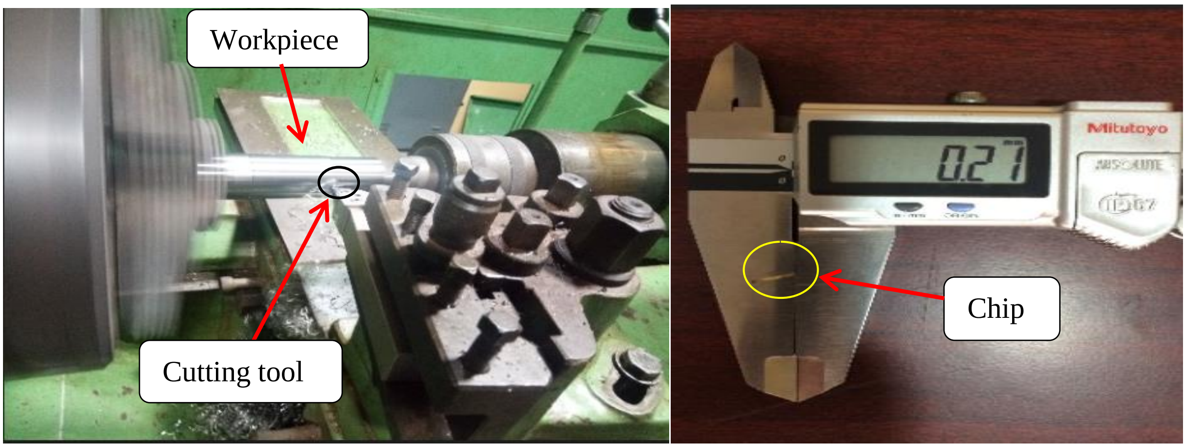

Figure 1. (a) Experimental set up (b) Chip thickness measuring instrument (Digital Vernier calliper)

The chip thickness measured by digimatic caliper manufactured by Mitutoyo Company (Made in Japan) having measuring range between (0-300mm / 0-12inch) and minimum indication value (0.01mm / 0.0005inch). The L9 orthogonal array was used as the design of the experiment. The range of cutting speed is 46- 102 m/min, the axial cutting feed is 0.04-0.2 mm/rev and depth of cut is 0.2-0.4 mm and the schematic diagram of turning process shown in the Fig. 1.

3. Analysis of Chip reduction coefficient

Generally, in the turning of any materials continuous, discontinuous and continuous with built-up-edge chips produce [16]. In the turning process, the materials ahead the cutting insert is compressed all sided and deformation takes place in the form of a chip. The chip thickness (a_2) is always larger than the thickness of uncut chip (a_1). The ratio of the chip thickness to the thickness of uncut chip known as the chip reduction coefficient (ξ) shown in the equation in (1) [16].

$$\xi = \frac{a2}{a1} \tag{1}$$

Where a_1 = feed . Sinϕ, and $\phi = 95^0$

If the value of (ξ) is more than more force and energy required to cut the materials. So it's very important to reduce the (ξ) without influence the productivity. So chip reduction coefficient is important machinability aspects in machining area. From the main effect plot for ξ, it was clearly noted that cutting speed and feed rate are inversely proportional to chip reduction coefficient. With the increment in speed and feed the chip reduction coefficient decreases. Taking into account the trend of the depth of cut, all the values of ξ generated lie very proximal or lie on the mean line without any sign of variation. So the depth of cut is not relevant for chip reduction coefficient shown in Fig. 2.

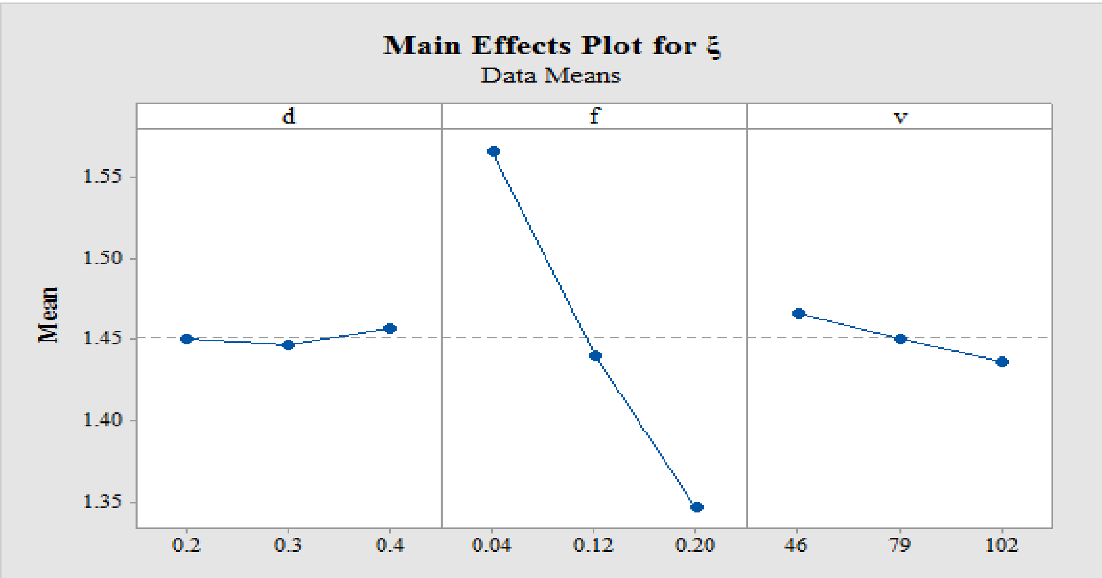

Figure 2. Main effect plot for chip reduction coefficient

4. Linear Regression Modelling

To relate a mathematical relationship between cutting parameters and responses, linear regression analyses were performed and further the following equations were developed:

$\xi = 1.64649 + 0.0333333\, d + 1.375\, f - 0.000533586\, v$
R-Sq = 99.10% R-Sq (pred) = 96.98% R-Sq (adj) = 98.57%

From the linear regression model it was observed that R-Sq value (99.10%) is very close to R-Sq (adj) value (98.57%) and both the values were close to the R-Sq (pred) value which signifies the validation of the model. In this model R-Sq value approaches to unity (100%), the desired output response model is fitted closely and effectively with the actual experimental result data. The graph plotted between experimental observation and chip reduction coefficient signifies that experimental data and predicted data lie close to each other without any significant deviation shown in Fig. 3. Especially at trail no. 3, 6 and 7 the experimental and predicted value is the most proximally placed. This signifies that the model used for prediction is significant. Fig. 4 shows the various residual plots for chip reduction coefficient were plotted using the MINITAB-17 software. The normal probability plot shows that the residual value lay very close to the mean line, which indicates the validation of experimental values. Overall residuals plot confirms the significant establishment of the model to predict the results correctly.

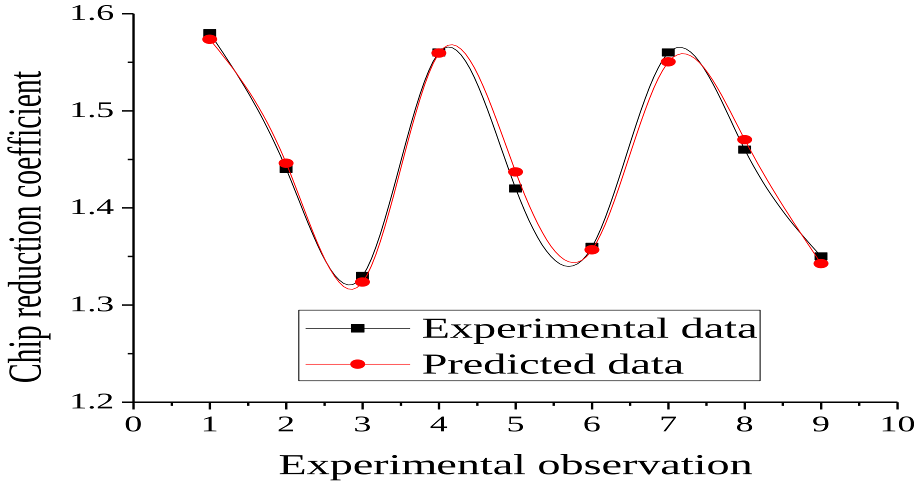

Figure 3. Compression graph of chip reduction coefficient between experimental & predicted data

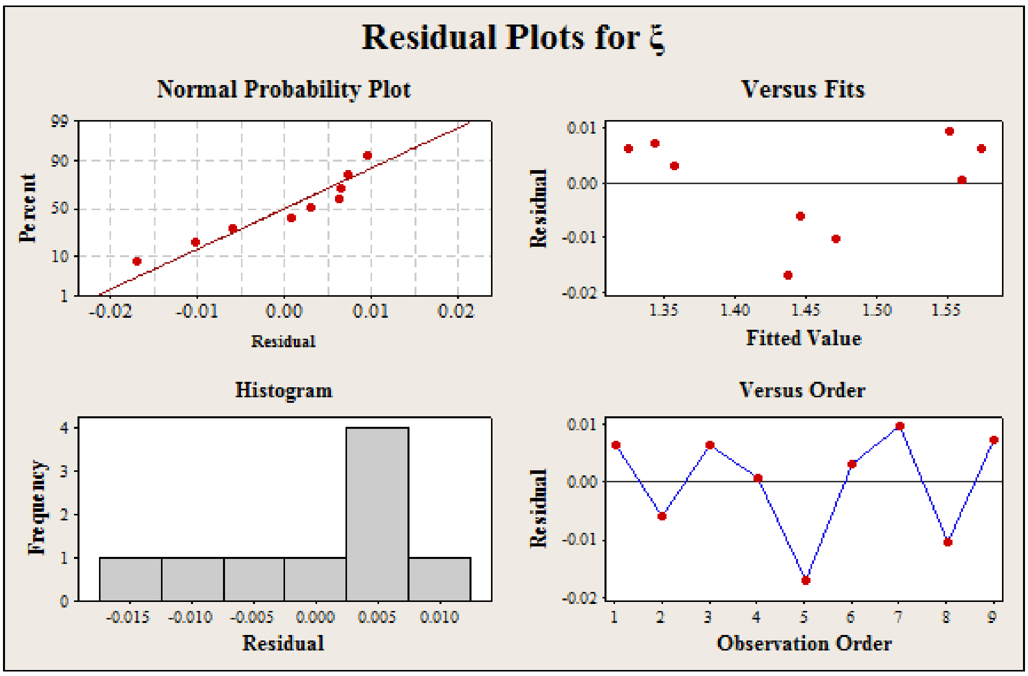

Figure 4. Residual plots for chip reduction coefficient

ANOVA method is used to determine the influence of given input parameter from a series of experimental results for a machining operation and also used to decode the experimental data. ANOVA is also used to determine the percentage contribution of the individual parameter, which is an advantage over Taguchi method. Here from Table 1, the P value (0.000015) for regression is below the standard value of 0.05 (95 % of confidence level) which ensures that the established model is valid. The contribution of feed on chip reduction coefficient is highest among all input variables which confirm that the feed is the most dominating term associated with chip reduction coefficient.

Table 1. Model ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Regression	3	0.0740202	0.0740202	0.0246734	184.490	0.000015	
D	1	0.0000607	0.0000667	0.0000667	0.498	0.511696	0.090
f	1	0.0726000	0.0726000	0.0726000	542.850	0.000003	97.20
V	1	0.0013535	0.0013535	0.0013535	10.121	0.024502	1.81
Error	5	0.0006687	0.0006687	0.0001337			0.90
Total	8	0.0746889					

5. Taguchi Optimization

The Taguchi design is power full design mostly acknowledged and used in engineering investigation and optimization. In Taguchi method used an orthogonal array to reduce the total number of experiment also eliminates the influence of uncontainable aspects.

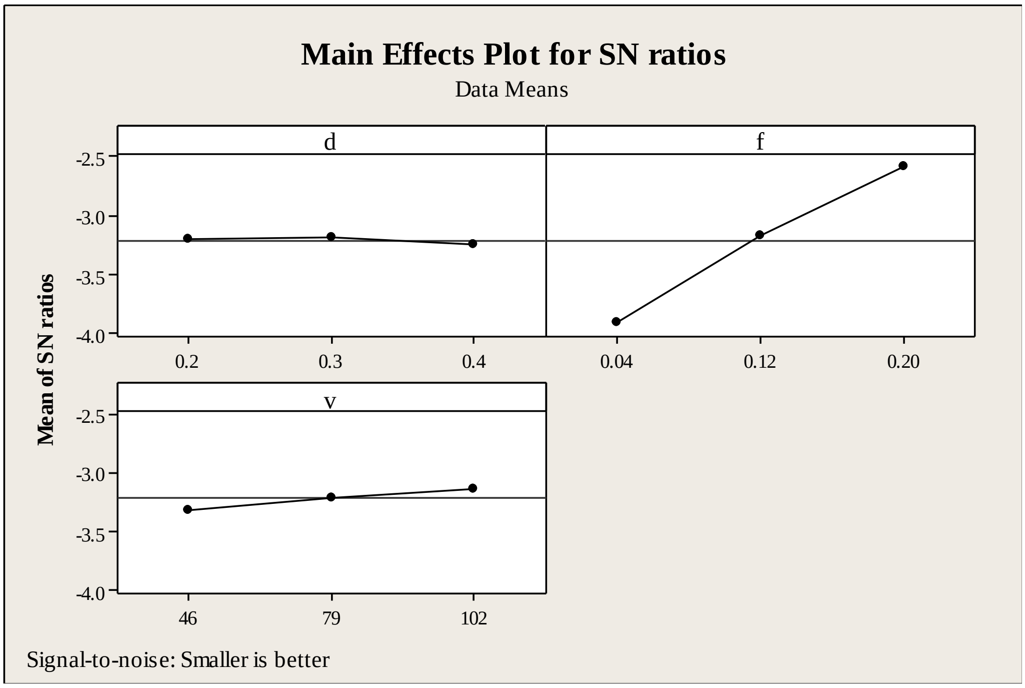

Figure 5. Main effect plots for S/N ratio

The advantaged of using the Taguchi method lessen the total number of test, less the experimental time, reduction in the production cost, and main advantage of this method is simple and precision [Manivel and Gandhinathan]. Taguchi (1990) design of the experiment is joined with the orthogonal array to analysis the complete parametrs within a lesser number of investigation tests. For investigation of S/N ratio Taguchi cites three types of performance structures (1) Lower the better,

(2) Higher the better, and (3) Nominal the better. In this work lower the better condition chosen to attain the optimal parameters during the turning process. From the main effect plot for S/N ratio the optimal cutting parameter combination is found to be d3-f1-v1 i.e (d = 0.4 mm; f = 0.04 mm/rev; v = 46 m/min). From the main effect plots for S/N ratio it was found that depth of has no significant effect on chip reduction coefficient as all its values lay proximal to the mean line whereas feed and speed are dominant as displayed in Fig. 5.

6. Conclusion

The following conclusions were drawn on the basis of an experimental investigation carried out in this present study.

- In metal cutting operation, Taguchi design of experiments was very efficiently used in optimization of input cutting parameters.
- The optimal parameter setting for better chip reduction coefficient is found to be $d3$-$f1$-$v1$, which denotes to a depth of cut (0.4 mm), feed (0.04 m/rev) and speed (46 m/min) and corresponding chip reduction coefficient is found to be 1.52.
- The regression model developed for prediction stands valid and the predicted value was found proximal to the experimental values.
- In this model R-Sq value approaches to unity (100%), the desired output response model is fitted closely and effectively with the actual experimental result data.
- From this present experimental investigation, it was concluded that with increment in feed and speed the chip reduction coefficient decreases, while the depth of cut has no significant effects.

Reference

[1] Gao C and Zhang L 2013 Effect of cutting conditions on the serrated chip formation in high-speed cutting *Machining Science and Technology* **17** pp 26–40

[2] Hua J and Shivpuri R 2014 Prediction of chip morphology and segmentation during the machining of titanium alloys *Journal of Materials Processing Technology* **150** pp 124–133

[3] Sutter G and List G 2013 Very high speed cutting of Ti–6Al–4V titanium alloy – change in morphology and mechanism of chip formation *International Journal of Machine Tools & Manufacture* **66** pp 37–43

[4] Daragusch M, Sun S, Kim J, Li T, Trimby P and Cairney J 2018 Effect of tool wear evolution on chip formation during dry machining of Ti-6Al-4V alloy *International Journal of Machine Tools and Manufacture* **126** pp 13–17

[5] Bai W, Sun R, Roy A and Silberschmidt V 2017 Improved analytical prediction of chip formation in orthogonal cutting of titanium alloy Ti6Al4V *International Journal of Mechanical Sciences* **133** pp 357–367

[6] Wu H and To S 2015 Serrated chip formation and their adiabatic analysis by using the constitutive model of titanium alloy in high speed cutting *Journal of Alloys and Compounds* **629** pp 368–373

[7] Sun S, Brandt M and Dargusch M 2010 Machining Ti–6Al–4V alloy with cryogenic compressed air cooling *International Journal of Machine Tools & Manufacture* **50** pp 933–942

[8] Aramcharoen A 2016 Influence of cryogenic cooling on tool wear and chip formation in turning of titanium alloy *Procedia CIRP* **46** pp 83 – 86

[9] Sahoo A K and Sahoo B 2013 Performance studies of multilayer hard surface coatings (TiN/ TiCN/Al2O3/TiN) of indexable carbide inserts in hard machining: Part-II (RSM, grey relational and techno economical approach) *Measurement* **46** pp 2868–2884

[10] Kumar S M and Kulkarni S K 2017 Analysis of Hard Machining of Titanium Alloy by Taguchi Method *Materials Today: Proceedings* **4** pp 10729–10738

[11] Sulaiman M A, Haron C C H, Ghani J A and Kasim M 2013 Optimization of Turning

Parameters for Titanium Alloy Ti-6Al-4V ELI Using the Response Surface Method (RSM) *Journal of Advanced Manufacturing Technology* **7,2** pp 11-28

[12] Ramana M V 2017 Optimization and Influence of Process Parameters on Surface Roughness in Turning of Titanium Alloy under Different Lubricant Conditions *Materials Today: Proceedings* **4** pp 8328–8335

[13] Gupta M, Sood P, Singh G and Sharma V 2017 Sustainable Machining of Aerospace Material - Ti (grade-2) alloy: Modelling and Optimization *Journal of Cleaner Production* pp 1-17

[14] Bandapali C, Sutaria B, Bhatt D and Singh K 2017 Experimental Investigation and Estimation of Surface Roughness using ANN, GMDH & MRA models in High Speed Micro End Milling of Titanium Alloy (Grade-5) *Materials Today: Proceedings* **4** pp 1019–1028

[15] Kumar R, Sahoo A k, Mishra P C and Das R K 2018 Comparative investigation towards machinability improvement in hard turning using coated and uncoated carbide inserts: part I experimental investigation *Advance in Manufacturing* **doi.org/10.1007/s40436-018-0215-z**

[16] Chattopadhyay AB 2017 Machining and Machine Tools 2_{nd} edition, *ISBN:* **978-81-265-6474-3**