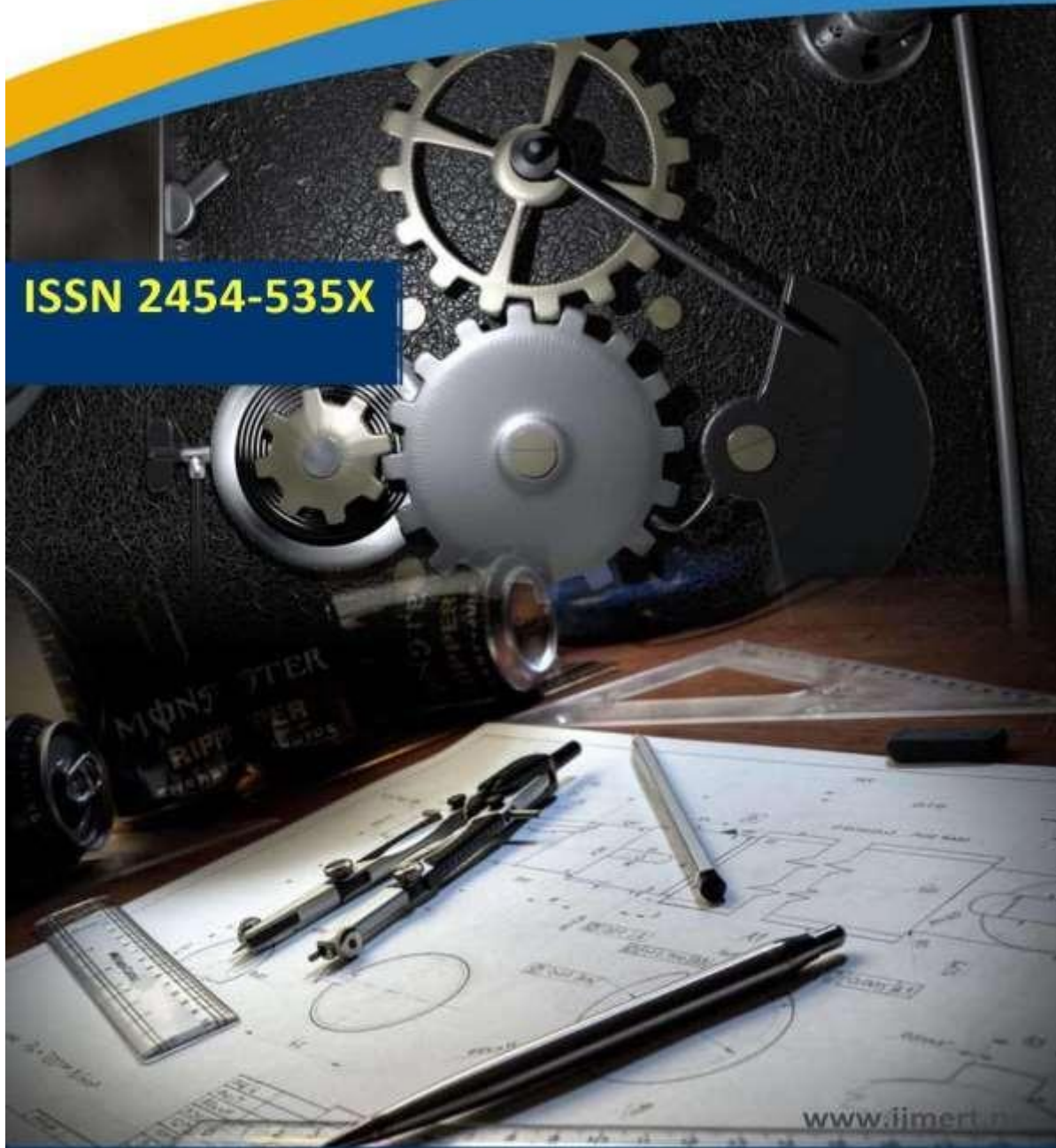




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Titanium 6246 Drillability from a Chip Formation Perspective

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ABSTRACT: Machinability is the root of the phrase "drillability," which is used in reference to drilling. This work suggests an alternative interpretation of drillability, namely the creation of chips, which has never been seen before for titanium alloy 6246 material. The fundamental understanding of this material's machinability, which has been scarcely known up until now, will be expanded by this study. The following variables were thought to be influencing the drillability: feed rate, cutting speed, drilling depth, cooling agent application, and material heat treatment before drilling. The studies were designed using the Taguchi method, and an analysis of variance was performed to determine how each parameter affected drillability. The degree of segmentation is a measure of how easy chips are to break. Minitab analysis reveals

INTRODUCTION

Regarding Ti-6246. Titanium alloys have several benefits, including high temperature tolerance, resistance to corrosion, and biocompatibility [1]. Ti-6Al-4V, one of the alpha-beta titanium alloys, is currently the most commonly used titanium alloy. On the other hand, titanium alloy 6Al-2Sn-4Zr-6Mo, also known as Ti-6246, is a relatively recent development from the same group and shares nearly identical mechanical and physical properties with Ti-6Al-4V [2].

EXPERIMENTATIONS METHOD

Design of experiment used. The Taguchi method would be used to design the experiments. It is compact and concise design of experiments, yet it proved to be useful tool to optimize the parameters which would result in optimum results.

Parameters variation. Some machining parameters would be varied: depth of drilling (10 mm, 30 mm, and 45 mm), cutting speed (27 m/min, 35 m/min and 50 m/min), feed rate (0.08 mm/rev, 0.11 mm/rev and 0.15 mm/rev) and either drilling with or without coolant. The parameter variations applied were between the range value suggested by the tool manufacturer. The tool used was

Compared to Ti-6Al-4V, it possesses superior corrosion resistance [3]. Both alloys are materials that are difficult to process. Ti-6Al-4V is more machine-friendly than Ti-6246 [4]. But compared to Ti-6Al-4V, Ti-6246 is more heat treatable. With the right heat treatment, Ti-6246 shows more promise as an easier-to-machine titanium alloy than the most widely used ones. Thus, heat treatment would be done in this investigation before drilling.

TiAlN carbide coated insert drill which was processed by PVD coating as recommended by some previous researchers [16], [17]. A milling center was employed for drilling.

Method of observation. The chips were collected from each experimentation than observed macroscopically and microscopically both by optic microscope and scanning electron microscopy. For microscopic observation, the chips were prepared by holding it on a ring and then hot mounted in a bakelite hot mounting machine. Proper grinding, polishing and etching were carried out prior to microscopical observations. Hardness of

the chips were measured using micro Vickers with indentation of 100 g for 10

second.

RESULTS AND DISCUSSION

The Heat Treatment

There is a curve line in a pseudo-binary of alpha + beta titanium alloy, named by beta transus line. According to Lutjering the beta transus temperature for Ti-6246 is 940°C [18]. As Ti-6246 is among the $\alpha+\beta$ titanium alloy, it will pass through the martensite start line when being heated to a certain temperature or when being cooled down as shown in Figure 1. Therefore, the heat treatment should consider this line. According to Froes [19], the Ms line is correspond to the Molibdenum equivalent (Mo eq) which is expressed by Bania [20] as follows:

$$\begin{aligned} Mo(eeq.) = & 11.00 [Mo] + 00.22[Ta] + 00. \\ & 2222[Nb] + 00.44[WW] + 00.6666[V] + 11. \\ & 2222[Cr] + 11.2222[NNN] + 11.66[Mn] \\ & + 11.66[Co] + 22.22[Fe] \end{aligned}$$

As other element in this equation is equal to zero, therefore Mo (eq) = 6%.

The interpolation from Froes in Figure 2 result in the Ms temperature of this alloy is 662°C. The heat treatment, therefore, will be made upper 940°C, below 662°C and between both these temperatures.

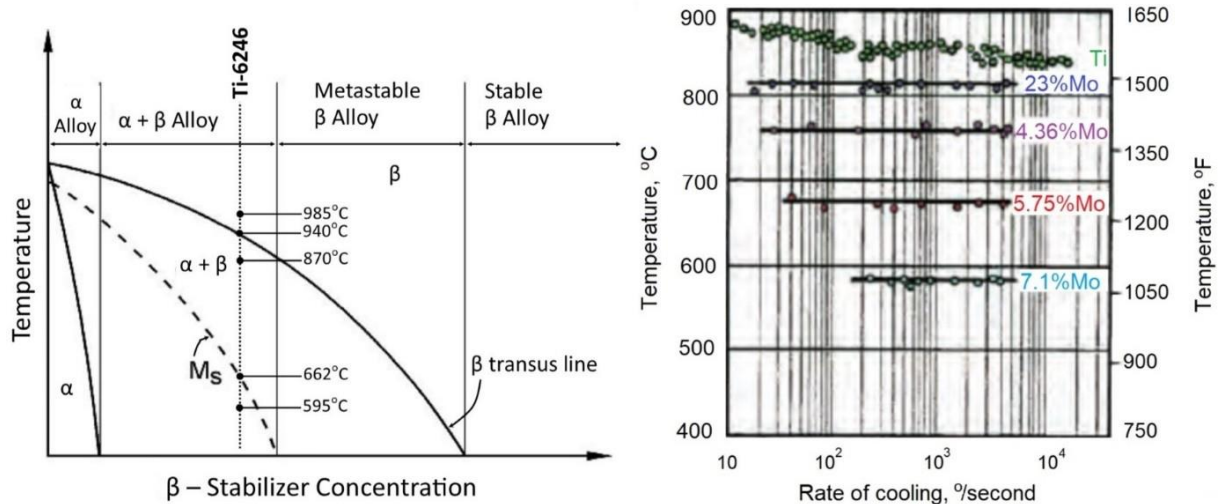


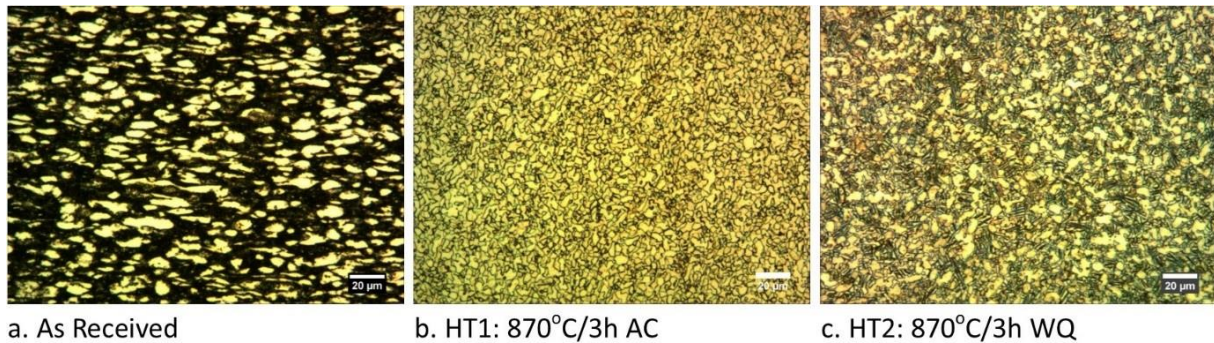
Figure 1. (a) Pseudo-binary of alpha + beta titanium alloy (From Lutjering with modification) and (b) the cooling rate was affected by molybdenum content of the material but it is independent each other (from Froes).

Preliminary observation shown that heat treatment at 595°C did not give significant different with the as received one in term of microstructure and hardness and so do the heat treatment at above beta transus temperature (945°C). Therefore, both heat treatments were excluded from the design of experiments.

Microstructure and mechanical properties of different heat treatments

Based on preliminary research, three main heat treatments were chosen, which shown different microstructure and were chosen out of several trials, i.e. (i) heated at 870°C then followed by furnace cooling, (ii) heated at 870°C then followed by water quenching and (iii) as received. For the sake of simplicity those three conditions will be termed as HT1, HT2 and AR respectively. The third option was no heat treatment as for default and standard condition. The samples were hold at those chosen temperature for three hours to ensure that microstructure uniformity. The comparison of microstructure of the chosen treatments is presented in the Figure

2. The hardness measurement using Vickers Micro Hardness showing their average value are 318 HV, 311 HV and 289 HV respectively. Reducing in the hardness hopefully followed by increasing drillability.



a. As Received

b. HT1: 870°C/3h AC

c. HT2: 870°C/3h WQ

Figure 2. Comparison of three microstructures of different treatment prior to drilling: (a) as received, (b) hold at temperature for 870°C followed by air cooling, (c) hold at temperature of 870°C for three hours followed by water quenching.

It is obvious that both heat treatments resulting in different microstructure to that of as received. They are finer grains. When Ti-6246 alloy are heated above the beta transus, the microstructure changes from alpha + beta to fully beta. Then, when it is cooled it will return to alpha + beta. At slow cooling the microstructure become smooth grains due to suffice time for the beta to transform. Whereas, at the rapid cooling, the beta structure is still predominate. The beta structure only possible to remain at the room temperature when there is beta stabilizer element in the alloy, such as V. The hardness of the as HT2-ed treatment is lowest than that of the HT1-ed one. It accordance to the fact that alpha phase is harder beta phase [21].

The chips were observed using microscopy and SEM. A sample of chips form is presented in Figure 4. All of the chips form is serrated one similar to results of other researchers [22], [23], [24]. Then, the chips analyzed using the value of serration degree. This parameter was introduced by Wang and Liu [25], Zang et al.[26], and Liu et al. [27]. It is comparing between the un-bonded part of the chip to the entire high one.

$$Gs = \frac{H-h}{H} \times 100\%$$

Where Gs is degree of serration, H represent the top peak of the chip, whereas h denotes the bottom peak one, and D is chips segment thickness. The Gs value were averaged from about 20 data measurements to ensure the validity.

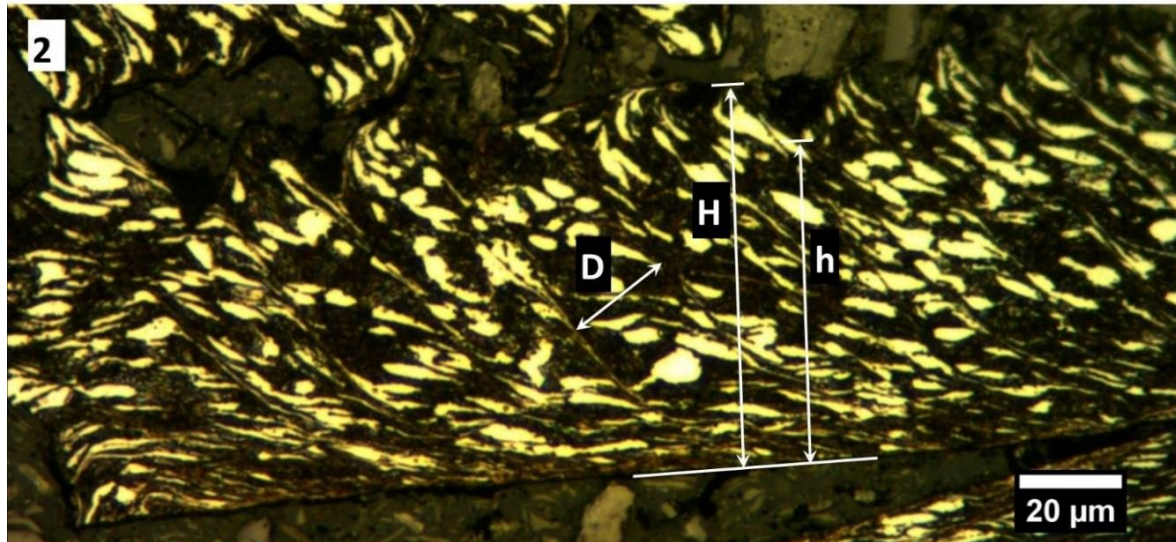


Figure 3. A sample of chips and the dimension for measuring the degree of serration Taguchi analysis

Result of measurement and calculation of Gs for each combination of parameters used in experiments in conjunction with Taguchi design L18 is presented in Table 1 below.

Table 1. L18 Orthogonal Array, Experiment result and S/N ratio

DE	Clt	HT	h	Vc	fr	Gs (%)	S/N Gs
1	Off	AR	10	27	0.08	11.1	20.9
2	Off	AR	30	35	0.11	14.8	23.4
3	Off	AR	45	50	0.15	21.2	26.5
4	Off	HT1	10	27	0.11	8.7	18.8
5	Off	HT1	30	35	0.15	10.0	20.0
6	Off	HT1	45	50	0.08	14.0	22.9
7	Off	HT2	10	35	0.08	18.0	25.1
8	Off	HT2	30	50	0.11	14.7	23.4
9	Off	HT2	45	27	0.15	8.7	18.8
10	On	AR	10	50	0.15	44.6	33.0
11	On	AR	30	27	0.08	20.2	26.1
12	On	AR	45	35	0.11	16.4	24.3
13	On	HT1	10	35	0.15	9.7	19.8
14	On	HT1	30	50	0.08	15.7	23.9
15	On	HT1	45	27	0.11	9.1	19.2
16	On	HT2	10	50	0.11	12.0	21.6
17	On	HT2	30	27	0.15	14.3	23.1
18	On	HT2	45	35	0.08	14.3	23.1

The quality characteristic of the ‘lower is the better’ was computed according to the equation of Taguchi’s for the chosen characteristic.

$$\frac{S}{N} = \frac{1}{N} \sum_{i=1}^n 10 \log \left(\frac{y_i^2}{LB} \right) \dots$$

(Gs).

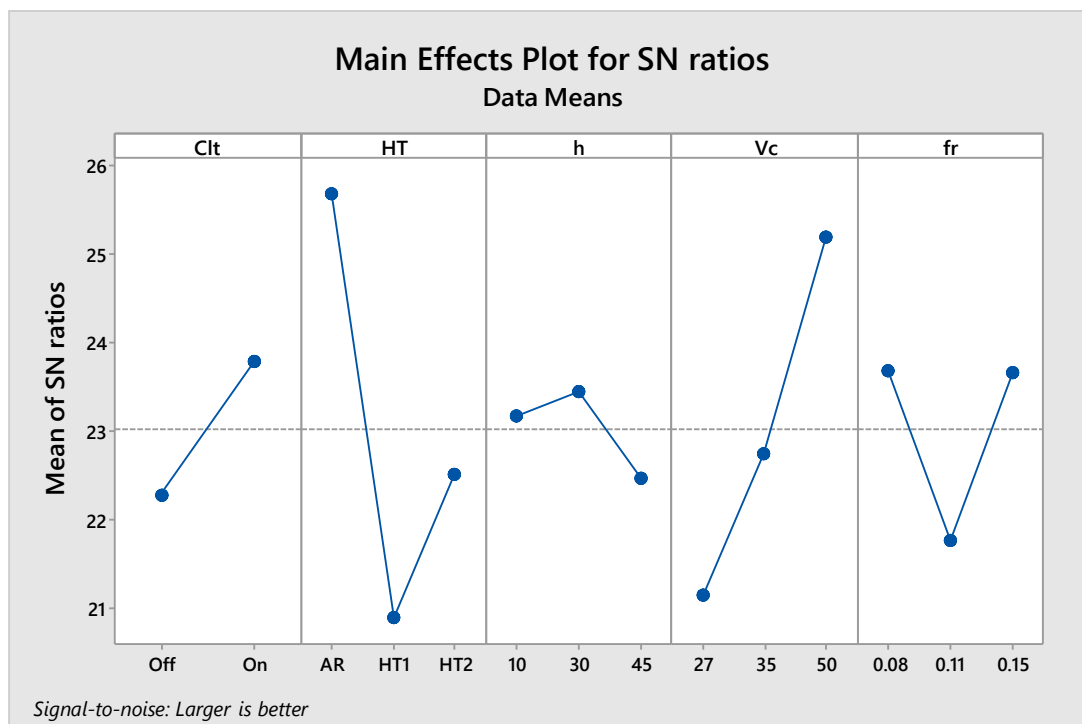
Here, Gs comparing between the unbonded part of the chip to its height, the lower the degree of segmentation indicates the higher possibly the chips be split off. In the contrary, the higher the degree of segmentation it be likely to create a long- and unbreakable- chips, which is detrimental. The shattered chips can contort along the drill body or even up to the spindle and ought to be taken away manually [28]. The values in the Gs column were the average of up and down of twenty calculations taken from chips of each set of experiment. As the characteristic of the quality of the ‘lower the better’ was chosen, the lowest value of Gs was desired. The S/N ratio values are listed in Table 1 for parameters of the degree of serration (Gs). The S/N value was engendered by Minitab 17 by measuring up the signal (controllable parameters or the factors which were involved in the experiments) and noise (uncontrollable parameters). Opposing from the measured value (in this research is Gs), the S/N ratio is not influenced by the elected characteristic of quality. It is permanently the higher the better, which means lessening the impact of the noise factors.

Table 2 demonstrates the response table for the S/N ratio for ‘lower is better’ which was acquired for diverse parameter levels. This table was obtained from Minitab 17 after generating the S/N ratio and choosing the ‘Gs’ as the response. The ‘Delta’ row values were calculated by subtracting the highest and the lowest S/N value of each factor. The higher the value of the delta means the higher the effect of the factor to the measured value

Table 2. Response Table for Signal to Noise Ratios of Gs

Level	Cl _t	HT	h	V _c	fr
1	22.28	25.70	23.18	21.14	23.68
2	23.79	20.90	23.45	22.75	21.77
3		22.51	22.47	25.21	23.66
Delta	1.51	4.80	0.98	4.07	1.91
Rank	4	1	5	2	3

It is obvious from Table 2 that the parameters which influenced the degree of serration by order are heat treatment (HT), cutting speed (V_c), feed rate (fr), coolant application (CT) and depth of drilling (h). The next step is determining the level of each parameter which may result the lowest Gs. Apparently from Table 2 and Figure 4 (of S/N ratio that result in maximum value) that the level should be chosen are: cutting speed of level 3 (50 m/min), feed rate of level 1 (0.08 mm/rev) and depth of drilling of level 1 (10 mm), while the block is best when drilled at as received and with applying coolant. Further consideration should be discussed upon the best level of feed rate. Between level 1 and level 3 of S/N for feed rate the different is only 0.02 (=23.68-23.66). By choosing the highest alternative value of feed rate (level 3 or feed rate of 0.15 mm/rev) means higher material removal rate or more economics drilling with a recklessness effect in compare to choosing feed rate of 0.08 mm/rev.

**Figure 4.** Mean of signal to noise ratio of each parameter.

Further step is to know which individual parameter would affect to the degree of serration value. For this, analysis of variance was carried out and the result is presented in Table 3.

The last column (P) showing contribution of each parameter (in percent) towards the measured value (Gs). It is evident that heat treatment is the most factor affecting the degree of serration. The smallest degree of serration would be achieved when drilling on block with HT1 treatment and the biggest when as received. It may be related to the microstructure of the blocks preceding the drilling. At as received condition, the microstructure is larger than that of as heat treated. Smaller grain size usually means higher shear energy separate the chips from the block. Smaller grain may also mean easier to separate within the chip along the grain boundary. Therefore, the degree of serration is lower.

Table 3. ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P, %
Cl	1	65.56	65.56	1.38	5.8
HT	2	329.43	164.71	3.46	29.0
h	2	35.77	17.89	0.38	3.2
Vc	2	227.86	113.93	2.40	20.1
fr	2	94.93	47.47	1.00	8.4
Error	8	380.47	47.56		33.6
Total	17	1134.02			100.0

Depth of drilling is the least affected to the degree of serration. The best result achieved when drilling of 30 mm deep, while the worst when depth of drilling was 45 mm. With naked eyes observation confirmed that when drilling deeper the chip form were zig zag, a denser form of the chips and between segments close to each other and more bonded. It may be related to how the chips were expelled from the cutting area through the helical flutes. The deeper the drilling the more difficult the chips to go out. Therefore, the chips tend to denser and form a zig zag pattern.

Comparison between chips with maximum dan minimum value degree of serration is presented in Figure 5.

The maximum value of Gs is reach up to 44.6%, while minimum value of 8.7%; these values were achieved on experiments number 4 and 10 respectively. It is evident that long and unbreakable chips (Fig 5-a) microscopically bonded each other or in another word it has lower Gs value (Fig 5-c). Short and broken chips (Fig 5-b), in contrast, as result of bigger Gs value.

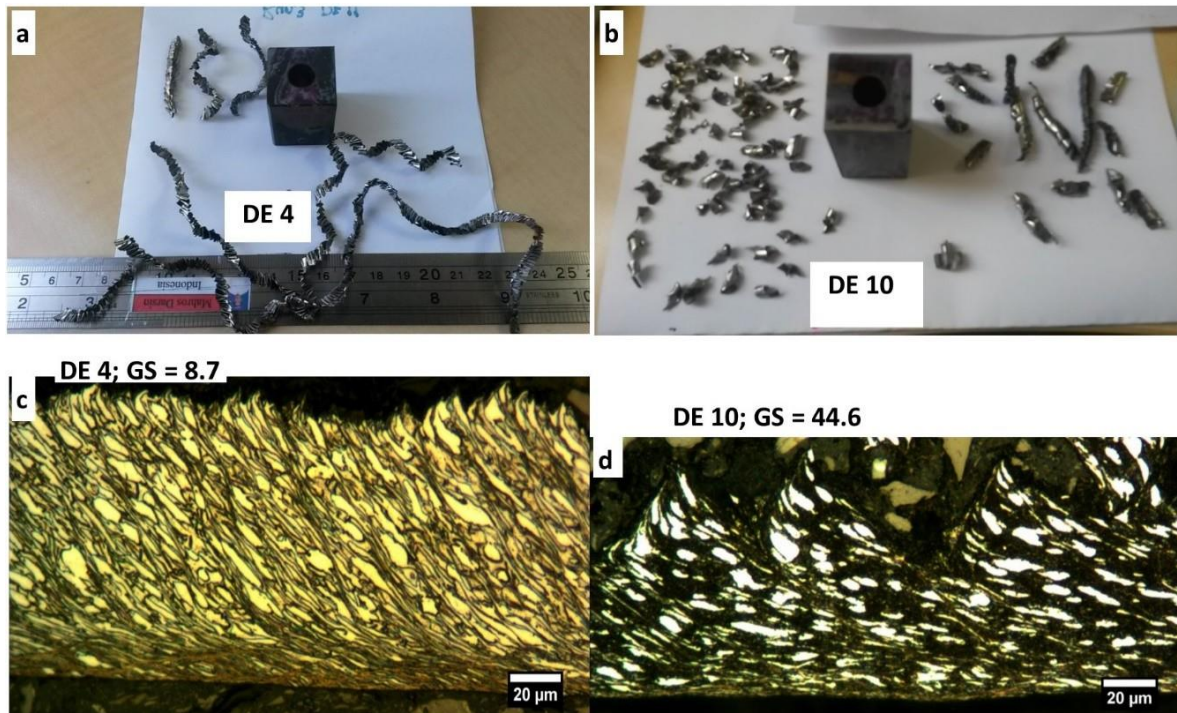


Figure 5. Photo macro of chips of long and barely unbreakable (a), short and broken ones (b). Photo micro of the lowest value of G_s (c) and highest one (d).

Mechanism of Chips Formation

There are two main forces work on the tool tip, thrust force (F_z) and torque (M_z) caused by feed rate (F_r) and linear cutting speed (V_c) applied on the drill (Fig 5a). Thrust force mainly (more than 50%) caused by works on chisel [29]. While torque is influenced by speed rotation and diameter of the drill. The chip formed due to shear force (τ cutting) that deform the material then separate it (Fig 6a). The serrated chips are caused by periodic thermoplastic shear instability happening within the primary shear zone. The shear instability happens when the rate of thermal softening exceeds the strain rate and strain hardening. Due to the shear process that takes place in very short time, the heat generated by severe plastic deformation in primary zone was not dissipated. Fig 6b shows clearly the primary shear zones (between chips segments) and the secondary shear zone at the bottom of the chip. The pattern of elongated grains clearly show that the chip experienced shear deformation [30-33].

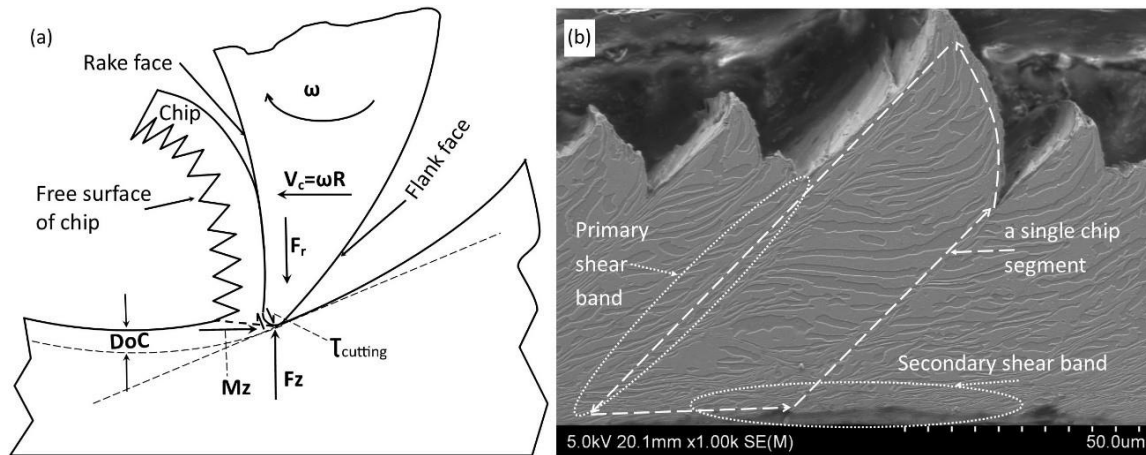


Figure 6. Mechanics of chip formation in drilling (a) and SEM photography of a serrated chip (b).

CONCLUSIONS AND RECOMMENDATIONS

From results and analysis discussion it is concluded that:

1. The drillability of titanium alloy 6246 could be achieved by selecting parameter for drilling as follow: cutting speed of 27 m/min and feed rate of 0.15 mm/rev when drilling at depth of 30 mm with coolant on, while the block should be heat treated by heating at 970oC hold for three hours then followed by air cooling.
2. Heat treatment is the most affecting parameter toward degree of serration.
3. The grains of chips experienced grain elongation.

REFERENCES

- [1] M. Donachie, *Titanium, a Technical Guide*, 2nd ed. ASM International, 2000.
- [2] MatWeb Material Property Data, "Titanium Ti-6Al-2Sn-4Zr-6Mo (Ti-6-2-4-6) BSTA," 2017. [Online]. Available: <http://www.matweb.com/search/datasheet.aspx?MatGUID=47cc69e4926f4177a13288cfc693bc99>. [Accessed: 03-Jul-2017].
- [3] R. Boyer, G. Welsch, and E. W. Collings, *Materials Properties Handbook: Titanium Alloys*. 1994.
- [4] M. Armendia, P. Osborne, A. Garay, J. Belloso, S. Turner, and P. J. Arrazola, "Influence of heat treatment on the machinability of titanium alloys," *Mater. Manuf. Process.*, vol. 27, no. 4, pp. 457–461, 2012.
- [5] E. A. Rahim, S. Sharif, Z. A. Ahmad, A. S. Mohruni, and I. A. Syed, "Machinability Investigation when Drilling Titanium Alloys," pp. 3–7, 2005.
- [6] S. Pervaiz, A. Rashid, I. Deiab, and M. Nicolescu, "Influence of tool materials on machinability of titanium- and nickel-based alloys: A review," *Mater. Manuf. Process.*,

- vol. 29, no. 3, pp. 219–252, 2014.
- [7] S. S. Gill and J. Singh, “Effect of deep cryogenic treatment on machinability of titanium alloy (Ti-6246) in electric discharge drilling,” *Mater. Manuf. Process.*, vol. 25, no. 6, pp. 378–385, 2010.
- [8] R. Muhammad, M. S. Hussain, A. Maurotto, C. Siemers, A. Roy, and V. V. Silberschmidt, “Analysis of a free machining alpha + beta titanium alloy using conventional and ultrasonically assisted turning,” *J. Mater. Process. Technol.*, vol. 214, no. 4, pp. 906–915, 2014.
- [9] R. Muhammad, A. Maurotto, A. Roy, and V. V. Silberschmidt, “Ultrasonically assisted turning of Ti-6Al-2Sn-4Zr-6Mo,” *J. Phys. Conf. Ser.*, vol. 382, p. 012016, 2012.
- [10] C. Siemers, B. Zahra, T. Leemet, and J. Rösler, “Development of advanced beta-titanium alloys,” in *Proceeding of the 8th AMMT '09 Conference*, 2009, pp. 1–7.
- [11] Z. Rihova, K. Saksl, C. Siemers, and D. Ostroushko, “Analyses of Wear Mechanisms Occurring During Machining of the Titanium Alloy Ti-,” *Word Acad. Sci. Eng. Technol.*, vol. 68, pp. 1515–1518, 2012.
- [12] O. Hatt, P. Crawforth, and M. Jackson, “On the mechanism of tool crater wear during titanium alloy machining,” *Wear*, vol. 374–375, pp. 15–20, 2017.
- [13] M. S. Hussain, C. Siemers, and J. Rösler, “Development of a free-machining ($\alpha+\beta$) titanium alloy based on Ti 6Al 2Sn 4Zr 6Mo,” in *Proceedings of the 37th International MATADOR Conference*, 2012, vol. I, pp. 197–200.
- [14] Z. Ullah, A. Ali, R.A. Khan, M. Iqbal. “Existence Results To A Class Of Hybrid Fractional Differential Equations”. *Matriks Sains Matematik*, vol. 1, no. 1, pp. 13-17, 2018.
- [15] L. Xu. “Study on Pc Continuous Girder Mechanical Properties Based on Tendon Tensioning Pattern”. *Acta Mechanica Malaysia*, vol. 1, no. 1, pp. 12-15, 2018.
- [16] B.Q. Li, Z. Li. “The Implement of Wireless Responder System Based on Radio Frequency Technology”. *cta Electronica Malaysia*, vol. 2, no. 1, pp. 15-17, 2018.
- [17] M. Elmnifi, M. Alshelmany, M. Alhammaly, O. Imrayed. “Energy Recovery from Municipal Solid Waste Incineration Benghazi - Case Study”. *Engineering Heritage Journal*, vol. 2, no. 1, pp. 19-23, 2018.
- [18] M. Darsin, T. Pasang, and Z. Chen, “Performance of TiAlN PVD coated carbide drill when drilling titanium 6246 alloy,” in *MATEC Web of Conferences*, 2017, vol. 109.
- [19] M. Darsin, T. Pasang, Z. Chen, and N. Zealand, “Forces Perspective of Drillability of Titanium Alloy,” *J. Energy, Mech. Mater. Manuf. Eng.*, vol. 3, no. 1, pp. 23–30, 2018.
- [20] S. Sharif and E. A. Rahim, “Performance of coated- and uncoated-carbide tools when drilling titanium alloy-Ti-6Al4V,”

- J. Mater. Process. Technol.*, vol. 185, no. 1–3, pp. 72–76, 2007.
- [21] Y. Isik, “Tool life and performance comparison of coated tools in metal cutting Yahya I ş ı k,” vol. 39, pp. 240–250, 2010.
- [22] G. Lutjering and J. C. Williams, *Titanium*, 2nd ed. Springer-Verlag BerlinHeidelberg, 2007.
- [23] F. H. Froes, *Titanium: Physical Metallurgy Processing and Application*, 1st ed., vol. 53. Ohio: ASMInternational, 1989.
- [24] P. J. Bania, “Beta titanium alloys and their role in the titanium industry,” *Jom*, vol. 46, no. 7, pp. 16–19, 1994.
- [25] C. Siemers, “Researchgate Question & Answer,” *Researchgate.net*, 2014. [Online]. Available: https://www.researchgate.net/post/Hello_everyone_my_question_is_why_martensite_in_Titanium_alloys_is_softer_than_B_phase. [Accessed: 01-Nov-2017].
- [26] D. Ostroushko, K. Saksl, C. Siemers, and Z. Rihova, “Chips of Ti-6Al-2Sn-4Zr-6Mo alloy – a detailed geometry study,” *Word Acad. Sci. Eng. Technol.*, vol. 6, no. 8, pp. 942–945, 2012.
- [27] P. Rokicki, Z. Spatz, L. Fusova, K. Saksl, C. Siemers, and B. Zhara, “Chip formation process of Ti-15V-3Al-3Sn-3Cr alloy,” in *Metal 2010*, 2010.
- [28] S. Joshi, P. Pawar, a. Tewari, and S. S. Joshi, “Tool wear mechanisms in machining of three titanium alloys with increasing b-phase fraction,” *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, 2014.
- [29] B. Wang and Z. Liu, “Serrated chip formation mechanism based on mixed mode of ductile fracture and adiabatic shear,” *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 228, no. 2, pp. 181–190, 2014.
- [30] J. Zang, J. Zhao, A. Li, and J. Pang, “Serrated chip formation mechanism analysis for machining oftitanium alloy Ti-6Al-4V based on thermal property,” *Int. J. Adv. Manuf. Technol.*, 2017.
- [31] H. Liu, J. Zhang, Y. Jiang, Y. He, X. Xu, and W. Zhao, “Investigation on morphological evolution of chips for Ti6Al4V alloys with the increasing milling speed,” *Procedia CIRP*, vol. 46, pp. 408–411, 2016.
- [32] F. Ke, J. Ni, and D. A. Stephenson, “Continuous chip formation in drilling,” *Int. J. Mach. Tools Manuf.*, vol. 45, no. 15, pp. 1652–1658, 2005.
- [33] J. S. Strenkowski, C. C. Hsieh, and A. J. Shih, “An analytical finite element technique for predicting thrustforce and torque in drilling,” *Int. J. Mach. Tools Manuf.*, vol. 44, no. 12–13, pp. 1413–1421, 2004.