Sains Malaysiana 43(1)(2014): 111–116

Effect of High-speed Parameters on Uncoated Carbide Tool in Finish Turning Titanium Ti-6Al-4V ELI

(Kesan Parameter Berkelajuan Tinggi terhadap Mata Alat Berkabida tak Bersalut bagi Larikan Titanium Ti-6Al-4V ELI)

M.A. SULAIMAN, C.H. CHE HARON*, J.A. GHANI & M.S. KASIM

ABSTRACT

In this work, the Sandvik uncoated carbide insert, CNGG 120408-SGF-H13A was used as a cutting tool in high-speed turning of titanium alloy Ti-6Al-4V ELI (extra-low interstitial) with hardness of 32 HRC. Wear is one of the problems that cannot be avoided in machining process. Therefore, the objective of this paper was to investigate tool-wear behavior of various cutting-speed values (high-speed range) on the tool life of the cutting tools, especially in finishing titanium alloy. The experiments were performed under flooded coolant condition using water-based mineral-oil. The cutting speeds employed were 120, 170 and 220 m/min. The feed rate was constant at 0.2 mm/rev and the depth of cut was 0.4 mm. Based on the results, the highest cutting speed of 220 m/min caused the highest wear rate. By linking the machine operations and the tool life curves obtained using flank wear data, the wear behavior of uncoated carbide was described.

Keywords: Coolant; high speed turning; Ti-6Al-4V ELI; uncoated carbide

ABSTRAK

Dalam kajian ini, mata pemotong karbida tidak bersalut buatan Sandvik; CNGG 120408-SGF-H13A telah digunakan sebagai alat pemotongan dalam larikan kelajuan tinggi terhadap titanium aloi Ti-6Al-4V ELI (tambahan rendah celahan) yang mempunyai kekerasan 32 HRC. Kehausan mata pemotong adalah salah satu masalah yang tidak dapat dielakkan dalam proses melarik. Oleh itu, objektif kajian ini adalah untuk melihat kelakuan kehausan mata pemotong pada pelbagai nilai kelajuan pemotongan (pada julat kelajuan tinggi) terhadap jangka hayat mata pemotong terutama untuk proses larikan akhiran titanium aloi. Eksperimen ini telah dilakukan di bawah keadaan penyejuk banjir dengan menggunakan minyak mineral berasaskan air. Kelajuan pemotongan adalah 120, 170 dan 220 m/min. Sementara itu, kadar suapan adalah malar pada kadar 0.2 mm/pusingan dan kedalaman pemotongan pada 0.4 mm. Berdasarkan keputusan yang diperoleh, didapati bahawa kelajuan pemotongan tertinggi, 220 m/min mengakibatkan kadar kehausan yang tertinggi pada mata pemotong. Dengan menghubungkan operasi pemesinan dan keluk hayat mata pemotong yang diperoleh dengan menggunakan data haus rusuk, kelakuan haus karbida tidak bersalut telah diterangkan.

Kata kunci: Karbida tidak bersadur; larikan berkelajuan tinggi; pelinciran; Ti-6Al-4V ELI

INTRODUCTION

Titanium and titanium alloy are among the many alloy materials developed and used widely, especially in the field of aerospace, automotive, offshore industry, biomedical materials, oil exploration and nuclear tanks. Titanium alloy is classified as hard and expensive. It is characterized by unique strength weight and resistance to crack at high temperatures; decrease chemical properties; wear and corrosion resistant at high temperature and longer life. It can also be suitably used with composite structures (Boyer 1995; Che Haron & Jawaid 2005; Ezugwu 2005; Ezugwu & Wang 1997; Ezugwu et al. 2003, 2005; Jawaid et al. 1999, 2000; Machado & Wallbank 1990; Ribeiro et al. 2003). In this work the workpiece used is Ti-6Al-4V extra low interstitials (ELI) alloy, which has a higher purity grade than ATI Ti-6Al-4V alloy. This grade has low oxygen, carbon and iron contents which offers high strength and depth hardening ability. It is used in biomedical applications, such as surgical instruments and orthopedic implants and is the preferred grade for marine and also aerospace applications.

Some cutting processes such as milling and turning are used to machine this type of titanium alloy. Turning is a machining operation that removes materials from the workpiece using single-edge cutting tool to generate cylindrical shape or complicated surface profile (Groover 2007). High-speed machining (HSM) is one of the modern technologies that increase the efficiency, accuracy and quality of workpieces and sometimes decreases the costs and machining time compared with conventional cutting. At certain cutting speeds, the process is 5-10 times higher than conventional machining.

Research on machinability of titanium alloy is continuously conducted, focusing on performance (life of cutting tools, flank wear, crater-wear modes, wear and volume of waste), material and geometry of cutting tools (coated or uncoated cutting tools), selection enhancements continue to do research with a focus on research performance (the life of cutting tools, the flank wear, the crater wear modes, wear and the volume of waste), material and geometry of cutting tools (coated and uncoated cutting tools), selection of the cutting angle and radius, cutting (machining with lubricating or cooling and dry machining), machining at cutting speed, depth of cut and high feed rate (Ginting 2003; Jawaid et al. 1999; Nabhani 2001). In addition, measurement of resulting surface finish and component forces during cutting operations are important factors (Ezugwu et al. 2003).

Wear is one of the problems that cannot be avoided in machining process. Various types of wear occur on the cutting tools and serious attention for optimum machining investigation is given in the experiments, focusing on tool life. The cutting parameters are cutting speed, feed rate and depth of cut. Previous studies showed that the tool life of carbide decreased quickly at higher cutting speed. This result was strongly supported by Venkatesh in (1980), who performed tool-wear investigations on some cutting tool materials. The aim of this paper was to investigate the tool wear in turning of titanium alloy, Ti-6Al-4V ELI, especially in HSM. This paper shows the various cutting speeds can influence the tool life of uncoated carbide insert during the finishing process. The machining works were performed under flooded condition.

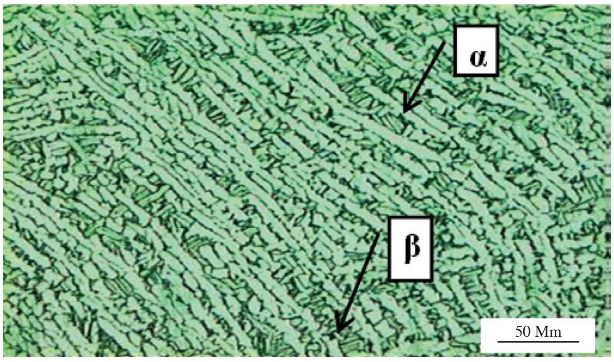


FIGURE 1. Microstructure of Ti-6Al-4V ELI

EXPERIMENTAL DETAILS

WORKPIECE MATERIAL

The workpiece material used in the experiments was a cylinder bar of an alpha-beta titanium alloy Ti-6Al-4V ELI, which is equiaxed at the α phase and surrounded by β in the grain boundary, as shown in Figure 1. The nominal compositions of the alloys in weight % include; 6.1 wt. % Al, 0.08 wt. % C, 0.22 wt. % Fe, 0.0031 wt. % H, 0.006 wt. % N, 0.12 wt. % O, 0.003 wt. % S, 0.03 wt. % Si, 3.8 wt. % V, 0.005 wt. % Y and Ti balance. The workpiece has a microstructure, which consisted of elongated alpha phase surround by fine, dark etching of beta matrix. This material possesses high strength and depth-hardened ability (317 HV). At least 3 mm of material top surface was removed to eliminate any surface defects and residual stress that can adversely affect the machining result.

CUTTING TOOL MATERIAL

A type of carbide insert with International Standards Organisations (ISO) designation CNGG 120408-SGF-H13A was used for the machining experiments. The cutting tool used was a straight tungsten carbide tool, which was an uncoated rhombic-shape, throw-away type with chip breaker. The insert consisted of 82.6 wt. % tungsten carbide, Wc with 16.4 wt. % of cobalt, Co as binder. Straight tungsten carbide (WC/Co) cutting tools have proven their superiority in almost all machining processes of titanium alloys (Ezugwu et al. 2003). The schematic geometry of the insert is shown in Figure 2.

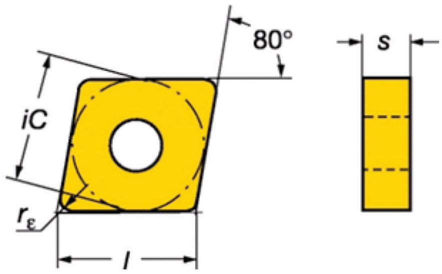


FIGURE 2. Schematic geometry of the insert used in the machining

MACHINING TESTS

All machining experiments were conducted on a Tornado T4 CNC lathe, using GE Fanuc Series 21i-TB as a controller. The cutting speeds were set at 120, 170 and 220 m/min, whereas the feed rate and depth of cut was keep constant at 0.2 mm/rev and 0.4 mm, respectively. The machining experiments were carried out in flooded condition using water-based mineral oil. The combination of parameters used are shown in Table 1. The detailed investigation of the worn-out tool was performed using scanning electron microscope (SEM). SEM was used to observe and analyze the damage to the cutting tools and the workpiece. Additionally, observations were made on the wear of cutting tools, cutting tool damage and microstructure of machined surface.

WEAR MEASUREMENT AND TOOL LIFE CRITERIA

The cutting parameters were established in the range of high speed turning, especially for finishing titanium alloy. To avoid concentrated impact loads that could trigger chipping when machining starts, a 2 mm precut entry was made for every new cutting pass. After the precut was done, a tested insert was used according to the combination in Table 1. The cutting operation was stopped at every 20 mm length. Then, the insert was dismounted from tool holder

TABLE 1. The combination of the cutting parameters

Run	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	120	0.2	0.4
2	170	0.2	0.4
3	220	0.2	0.4

and the tool wear was measured. The experiment for a particular insert was completed when the average flank wear Vb_{avg} reached 0.3 mm. These steps were repeated for all combinations. Flank wear (*Vb*) was measured using the 3D optical microscope Perthometer and the data of flank wear obtained from the experiment were analyzed. ISO has suggested a standard for tool-life testing (ISO 3685 1977). The following criteria were used as basis in rejecting an insert: Average flank wear reaches 0.3 mm or maximum flank wear reaches 0.6 mm; notch at cut depth reaches 1.00 mm; crater wear depth reaches 0.14 mm; surface finish on work material exceeds 6 mm centreline average and flaking or fracture occurs. In this experiment, a flank wear of 0.3 mm was regarded as tool-life criterion for all tested inserts.

RESULTS AND DISCUSSION

The discussion of the results are focused on the tool-wear behavior during high-speed turning of titanium alloy Ti-6Al-4V ELI. The results showed that flank wear increased with increase in cutting speed, in which the wear progressed more quickly at the highest cutting speed of 220 m/min, followed by the cutting speeds of 170 and 120 m/min. The flank wear-land versus cutting time in turning Ti-6Al-4V ELI using uncoated carbide tools is shown in Figure 3. A typical three-stage pattern of tool wear is shown, similar to the pattern reported by Jawaid et al. (1999) when titanium alloy was machined using coated and uncoated carbide tools. The wear occurred rapidly during the initial stage, gradually increased in the second stage and greatly increased at the final stage. The rapid increase at the initial stage was due to a small contact area between the cutting tool and the workpiece, which caused an increase in temperature at the cutting edge and some material were easily removed from the cutting tool (Che Haron et al. 2001; Gusri 2008). The cutting edge of an insert is subjected to a combination of high stress and high temperatures, which cause tool wear due to one or several mechanisms (Che Haron 2001). These mechanisms depend on cutting geometry, tool and workpiece material combinations and thermal loadings encountered.

TOOL WEAR

Titanium alloy Ti-6Al-4V ELI is a strong titanium alloy and has higher strength, depth of hardness and elevated temperature properties of up to 450°C. The temperature generated within the primary and secondary shear zones affects the wear rate of the tool materials. Hence, high cutting temperature often results in severe tool wear, such as plastic deformation, chipping and fracture at the cutting edge. Several types of wear mechanisms occur that can influence the tool wear and subsequently, the tool life when machining using Ti-6Al-4V ELI. The observed wear mechanisms were diffusion, abrasion, adhesion, chipping and plastic deformation.

In high-speed cutting of titanium alloy, the heat generated in the cutting zone is very high and in these experiments, coolant was employed to reduce the temperature. Some previous research cut the titanium alloy under dry condition, but they used the low cutting speed,

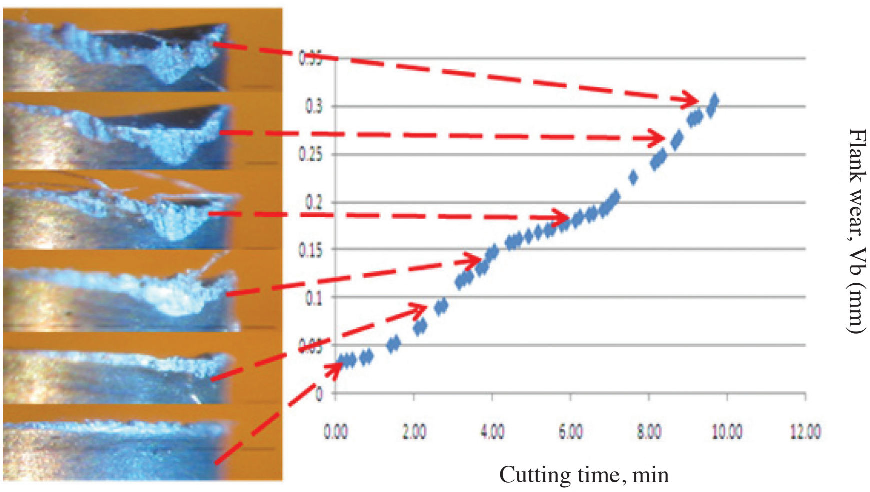


FIGURE 3. Flank wear-land, Vb (mm) vs. cutting time, (min)

normally below 90 m/min. Figure 4 shows the domain two types of wear on the cutting edge obtained using SEM technique (crater and flank wear) when machining titanium alloy. Flank face wear is caused by friction between the newly machined workpiece surface and the contact area at the tool flank. Based on smooth wear patterns on the flank face of the tested tool, the dissolution-diffusion wear mechanism is seen to be more predominant compared with other mechanisms, especially in high-speed cutting. On the other hand, crater wear normally occur at the tool-chip contact area (tool top surface) where the tool chip moves with friction force. A crater can also be formed by shearing on the rake face. The rake wear on the tool were resulted from dissolution-diffusion machining in high speed turning titanium alloy. Here higher temperature provided an environment for tool material atoms to diffuse beyond tool-workpiece interface, similar with previous research where the chip pulling apart a portion of the rake face in chip flow direction (Narutaki & Yamane 1993). In addition, the dissolution-diffusion wear predominated on the rake face of all the uncoated carbide (Dearnley 1986).

Figure 5 shows the final stage of flank wear-land pictures captured by a digital camera during measurement by 3D microscope Perthometer. The chipping occured at the cutting edge because of the heat generated during the high-speed cutting of titanium alloys. Additionally, higher stresses caused the chipping process on that area and abrasion process occured at some other places.

TOOL LIFE

The results from the machining experiment showed that the flank wear, rake wear and tool life were affected significantly by the cutting speed. Increase in cutting speed caused a large increase in cutting temperature at the cutting edge of the tools. The higher temperature generated caused the tools to lose their strength and plastic deformation occurred. Figure 6 and Table 2 show that the tool life for the highest cutting speed of 220 m/min is very short (2.34 min), followed by 170 m/min with 4.29 min and the lowest cutting speed of 120 m/min with approximately 16.79 min. However, according to ISO 3685, the tool life more than 2 min is an accepted value for machining an expensive material. Therefore, these tool life values are considered suitable for machining titanium alloy Ti-6Al-4V ELI. These cutting parameters and tool life values are presented in Table 2.

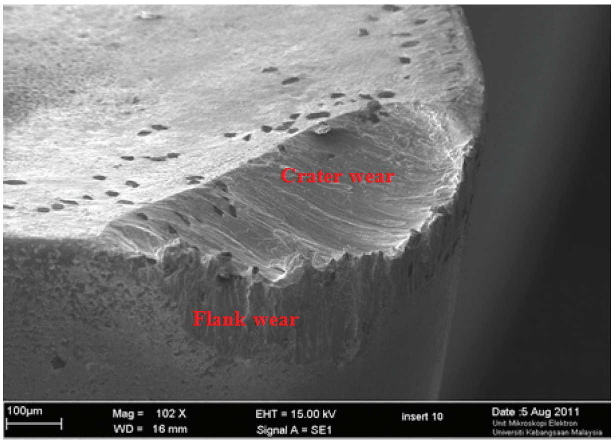
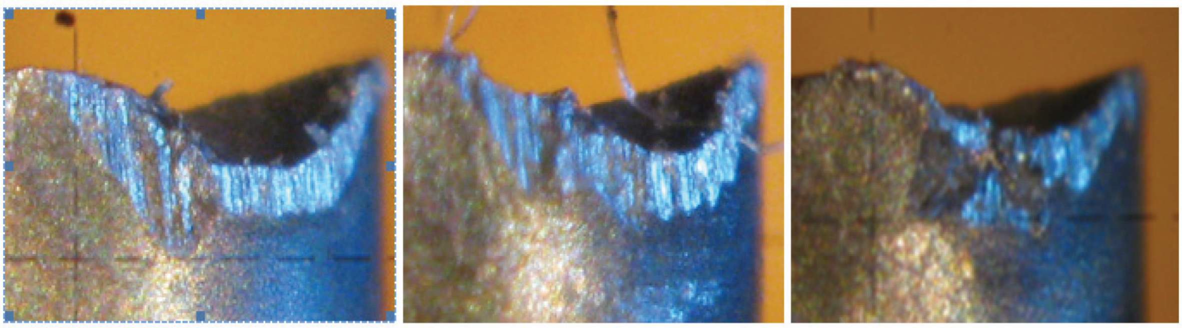


FIGURE 4. SEM micrograph (scale 100 µm) shows the flank and crater wear on CNGG 120408-SGF-H13A



(a) (b) (c)

FIGURE 5. Flank wear land, Vb were measured by 3D microscope Perthometer for: (a) V = 220 m/min, (b) V = 170 m/min and (c) V = 120 m/min

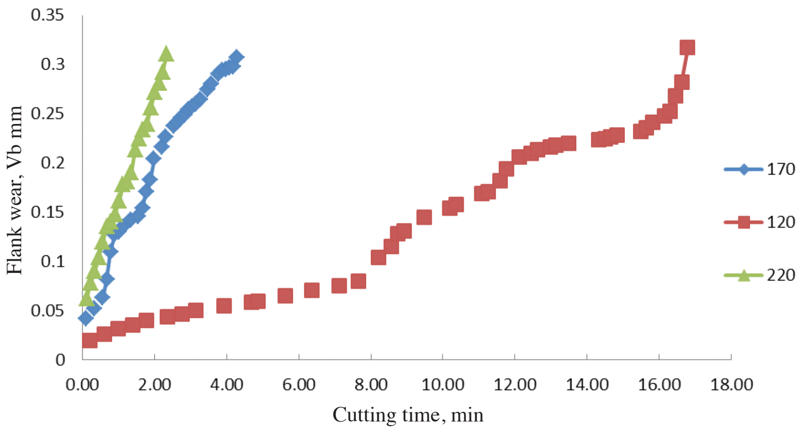


FIGURE 6. Cutting time, min for various cutting speeds (m/min) on tested inserts

TABLE 2. Cutting parameters were used in machining and its tool life

Run	Cutting speed Vc (m/min)	Feed rate F (mm/rev)	Depth of cut (mm)	Tool life (min)
1	120	0.2	0.4	16.79
2	170	0.2	0.4	4.29
3	220	0.2	0.4	2.34

CONCLUSION

Based on the experiment, the wear progression of uncoated carbide tools occurred generally in three stages: Initial stage, gradual stage and abrupt stage of wear. In this work, the width of flank wear-land, Vb_{avg} was set at 0.3 mm in reference to ISO 3685. The average flank wear, Vb_{avg} can be used as a factor in determining the tool life of all tested inserts. According to the graph, the cutting tool rapidly wears down with the increase in cutting speed, also related to the tool-life data. The uncoated carbide tool can be used in high-speed cutting of titanium alloy Ti-6Al-4V ELI but only in flooded condition. The cutting speed of 220 m/min was considered as the upper limit for uncoated carbide tool to finish turning titanium alloy because tool life at this speed is approximately 2.3 min.

ACKNOWLEDGEMENTS

We would like to thank Universiti Kebangsaan Malaysia in providing research fund (Grant No: UKM-GUP-BTT-07-25-171), equipment, material and technical support.

REFERENCES

Boyer, R.R. 1995. Titanium for aerospace: Rationale and application. *Advanced Performance Material* 2(4): 349-368.

Che Haron, C.H. 2001. Tool life and surface integrity in turning titanium alloy. *Journal of Material Processing and Technology* 118: 231-237.

Che Haron, C.H., Ginting, A. & Goh, J.H. 2001. Wear of coated and uncoated carbides in turning tool steel. *Journal of Materials Processing and Technology* 116: 49-54.

Che Haron, C.H. & Jawaid, A. 2005. The effect of machining on surface integrity of titanium alloy Ti-6%Al-4%V. *Journal of Materials Processing and Technology* 166: 188-192.

Dernley, P.A. & Grearson, A.N. 1986. Evaluation of principal wear mechanisms of cemented carbides and ceramics used for machining titanium alloy IMI 318. *Material Science and Technology* 2(1): 47-58.

Ezugwu, E.O. & Wang, Z.M. 1997. Titanium alloys and their machinability – A review. *Journal of Materials Processing and Technology* 68: 262-274.

Ezugwu, E.O. 2005. Key improvement in the machining of difficult-to-cut aerospace super alloys. *International Journal of Machine Tools and Manufacture* 45: 1353-1367.

Ezugwu, E.O., Da Silva, R.B., Bonney, J. & Machado, A.R. 2005. Evaluation of the performance of CBN tools when turning Ti-6Al-4V alloy with high pressure coolant supplies. *International Journal Machine Tools and Manufacture* 45: 1009-1014.

Ezugwu, E.O., Booney, J. & Yamane, Y. 2003. An overview of the machinability of aeroengine alloys. *Journal of Material Processing and Technology* 134: 233-253.

Gusri, A.I., Che Hassan, C.H. & Jaharah, A.G. 2008. The effect of dry machining on surface integrity of titanium alloy Ti-6Al-4V ELI. *Journal of Applied Science* 1: 121-127.

Ginting, A. 2003. Pemesinan hijau aloi titanium Ti-6242S dengan menggunakan perkakas pemotong pengisar hujung karbida. Tesis Dr. Falsafah, Jabatan Kejuruteraan Mekanik dan Bahan. Universiti Kebangsaan Malaysia (unpublished).

Groover, M.P. 2007. *Fundamentals of Modern Manufacturing*. 3rd ed. United States: John Wiley & Sons.

ISO 3685. 1977. *Tool Life Testing with Single-point Turning Tools*. Geneva: International Standard Organization.

Jawaid, A., Che Haron, C.H. & Abdullah, A. 1999. Tool wear characteristics in turning of titanium alloy Ti-6246. *Journal Material Processing and Technology* 92: 329-334.

Jawaid, A., Sharif, S. & Koksal, S. 2000. Evaluation of wear mechanism of coated carbide tools when face milling titanium alloy. *Journal of Materials Processing and Technology* 99(1-3): 266-274.

Machado, A.R. & Wallbank, J. 1990. Machining of titanium and its alloys - A review. *Journal of Engineering Manufacture* 204: 53-60.

Nabhani, F. 2001. Machining of aerospace titanium alloys. *Robotics and Computer Integrated Manufacturing* 17: 99-106.

Narutaki, N. & Yamane, Y. 1993. Machining of difficult-to-cut material. *International Journal Japan Soc. Prec. Engineering* 27(4): 307-310.

Ribeiro, M.V., Moreira, M.R.V. & Ferreira, J.R. 2003. Optimization of titanium alloy (Ti-6Al-4V) machining. *Journals of Materials Processing and Technology* 143-144: 458-463.

Venkatesh, V.C. 1980. Tool wears investigations on some cutting tool materials. *Journal Lubrication Technology* 102: 556-559.

C.H. Che Haron* & J.A. Ghani
Department of Mechanical and Material Engineering
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor Darul Ehsan
Malaysia

M.A. Sulaiman & M.S. Kasim
Department of Process
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka
76100 Hang Tuah Jaya
Melaka

*Corresponding author; email: chase@eng.ukm.my

Received: 21 March 2012
Accepted: 15 May 2012