

Development of α - β type titanium alloy Ti-4.5Al-2.5Cr-1.2Fe-0.1C-0.3Cu-0.3Ni having good forgeability and machinability.

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Development of a titanium alloy having excellent hot forgeability and machinability while having the same properties as Ti-64 alloy is effective in reducing the total cost of titanium parts. To develop a new alpha-beta type titanium alloy which has good hot forgeability, machinability and tensile properties equivalent to those of Ti-64 alloy at room temperature, Ti-4.5Al-2.5Cr-1.2Fe-0.1C-nCu-nNi (n=0 to 2) were prepared and evaluated.

The new alloy showed tensile properties equivalent to that of Ti-64 alloy at room temperature. On the other hand, the hot deformation stress of new alloy was about 30% lower than that of Ti-64 alloy, and the excellent deformability was confirmed. The addition of Cu and Ni to Ti-4.5Al-2.5Cr-1.2Fe-0.1C alloy suppressed the amount of wear of tool and improved the machinability. Tool life of new alloy machining is extended by about 1.5 times compared to that of Ti-64 alloy. Addition of Cu and Ni is considered to reduce the reactivity between tool and workpiece and improve machinability.

Keywords: alpha-beta type titanium alloy (α - β type titanium alloy), hot forging, machining

1. Introduction

The most common titanium alloy is Ti-6Al-4V alloy (hereafter Ti-64 alloy), which is widely used in many applications. In aircraft fuselage parts also, Ti-64 alloy is used mainly and some of which are manufactured with processes including hot forging and machining. However, the forgeability and machinability of this alloy are not good. In hot forging process, forging cracks may occur when forging temperature or deformation amount deviate from suitable range. Sometimes, due to the high deformation resistance, forging die may not be filled with the material and desired shapes may not be obtained. To prevent these defects, there are necessity of increasing the input weight or increasing the number of heating times of forging and it leads to increasing costs of manufacturing. In machining process, since machining of titanium alloys are more difficult than that of structural materials such as steel and aluminum, processing time become longer and frequency of cutting tool replacement is increased. As a result, productivity is decreased, and manufacturing cost is increased [1]. Therefore, development of a titanium alloy having excellent hot forgeability and machinability while having the same properties as Ti-64 alloy is effective in reducing the total cost of titanium parts.

An α - β type titanium alloy Ti-4.5Al-3.5Cr-0.5Fe-0.2C (hereafter EL-F alloy) had been developed. The EL-F alloy has good hot forgeability similar to commercially pure titanium and mechanical properties equivalent to those of Ti-64 alloy at room temperature [2, 3]. Based on the EL-F alloy, Ti-4.5Al-2.5Cr-1.2Fe-0.1C (hereafter Ti-531C) alloy has been developed. Machinability of Ti-531C alloy had been improved [4]. However, since machinability of Ti-531C alloy was inferior to that of Ti-64 alloy on some processing conditions, in this paper, further improvement of machinability was examined.

2. Experimental

Ingots about 150mm diameter x 220mm height were prepared by Cold Crucible Induction Melting (CCIM). Chemical compositions of ingots are Ti-531C alloy with small amounts of Cu and Ni addition, Ti-4.5Al-2.5Cr-1.2Fe-0.1C-nCu-nNi (n = 0 to 2.0), and shown in Table 1. The β transus of this alloy is about 980°C. These ingots were heated to β region, 1200°C, pressed to 110 mm height and forged to 140 mm x 180 mm x length in which the height direction of the ingot is parallel with the length

direction of the rectangle. These rectangle materials were heated to $\alpha+\beta$ region, 850°C, forged to 45 mm x 110 mm x length and annealed at 750°C for 24 hours.

Table 1 Chemical composition of alloys (preparation)

	Element (mass%)						
	Al	Cr	Fe	C	Cu	Ni	Ti
Ti-531C	4.5	2.5	1.2	0.1	–	–	Bal.
Ti-531C 0.1Cu-0.1Ni	4.5	2.5	1.2	0.1	0.1	0.1	Bal.
Ti-531C 0.3Cu-0.3Ni	4.5	2.5	1.2	0.1	0.3	0.3	Bal.
Ti-531C 0.5Cu-0.5Ni	4.5	2.5	1.2	0.1	0.5	0.5	Bal.
Ti-531C 1.0Cu-1.0Ni	4.5	2.5	1.2	0.1	1.0	1.0	Bal.
Ti-531C 2.0Cu-2.0Ni	4.5	2.5	1.2	0.1	2.0	2.0	Bal.

Tensile tests were conducted at room temperature conforming to ASTM E8 and compared with Ti-64 alloy annealed at 705°C for 2 hours.

To evaluate the hot forgability, flow stress and compression limit were evaluated with compression tests. The shape of specimen is cylindrical with a notch parallel to the height direction as shown in Fig. 1. In compression tests, specimens were heated at 880 °C for 50 minutes in air and cooled to 650 °C, it took about 27 seconds, followed by compression. Compression speed was 5 spm (strain rate $1\sim 2s^{-1}$) and compression ratio was 20~80%. Maximum compressibility is defined as the maximum compression ratio without visible surface cracks on notch.

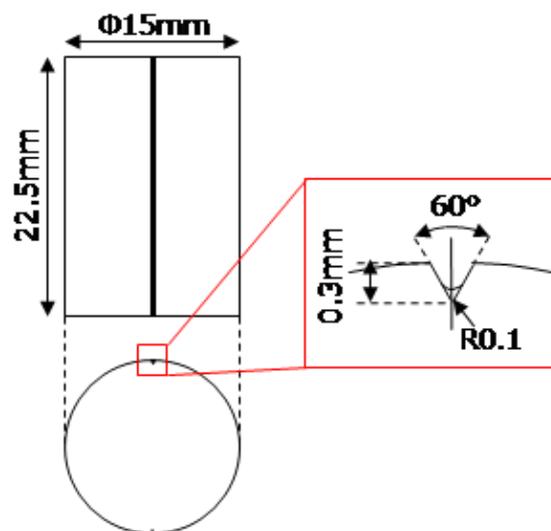


Fig. 1 Schematic illustration of the specimen for hot forgability evaluation.

Machining tests were conducted to evaluate machinability. Conditions and schematic illustration of the test are shown in Table 2 and Fig. 2, respectively. In this method, tool and workpiece contact intermittently. Additionally, turning process test as a continuous cutting in which the tool and the material continuously contact was also performed. The machinability was evaluated by the maximum wear on the flank of the tool [5].

Table 2 Conditions of a machining test

Tool	R390 (Ø20 mm, 1 tooth) cemented carbide tool (S30T)
Cutting speed, v_c	50, 75 m/min.
Radius depth of cut, a_e	3.0 mm
Axial depth of cut, a_p	1.0 mm
Feed, f_z	0.1 mm/tooth
Cutting length, l	max. 90 m

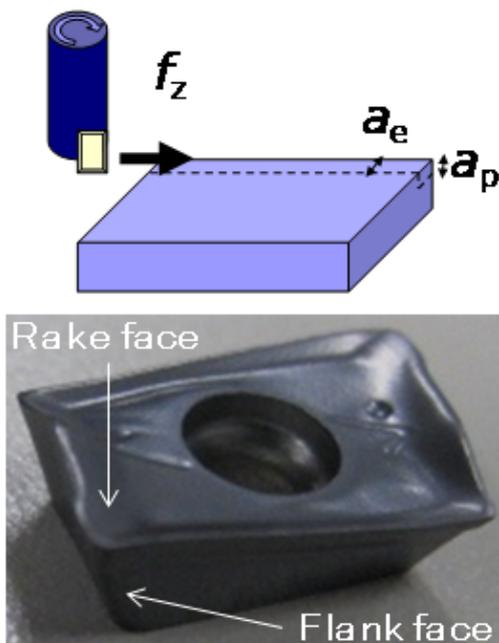


Fig. 2 Schematic illustration of machining test and photo of the machining tool.

3. Results and Discussions

Fig. 3 shows the tensile test results of Ti-6Al-4V, Ti-531C and Ti-531C-0.3Cu-0.3Ni alloys. Compared to Ti-6Al-4V alloy, equivalent tensile properties were obtained at room temperature.

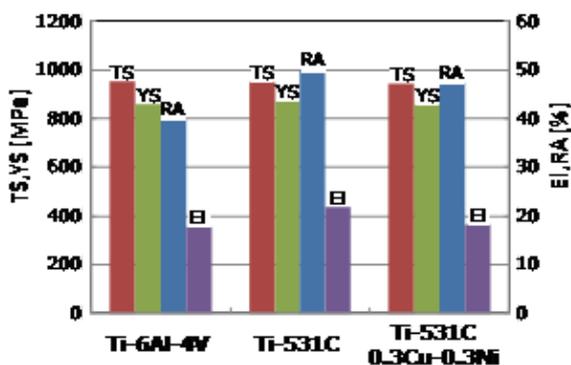


Fig. 3 Tensile properties at room temperature.

The maximum compressibility determined in the compression tests and photographs of the specimens after compression tests are shown in Fig. 4. Cracks were found in the notched part with Ti-64 alloy at 50% compression, but no cracks occurred in Ti-531C alloy and Ti-531C-0.3Cu-0.3Ni alloy even after 80% compression. Fig. 5 shows flow stress at 50% compression. At the conditions of this work, flow stress of Ti-531C alloy and Ti-531C-0.3Ni-0.3Cu alloy were about 30% lower than that of Ti-64 alloy. Fig.4 and Fig. 5 show that Ti-531C-0.3Ni-0.3Cu alloy has the same flow stress and plastic deformability as Ti-531C alloy and it is considered that Ti-531C-0.3Cu-0.3Ni alloy also has the same hot forgeability as Ti-531C alloy which has good forgeability in a hot forging test [6].

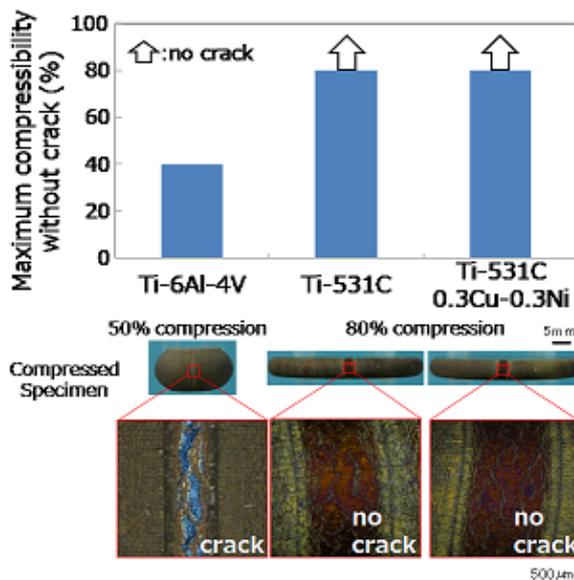


Fig. 4 The maximum compressibility and photographs of the specimens after compression tests.

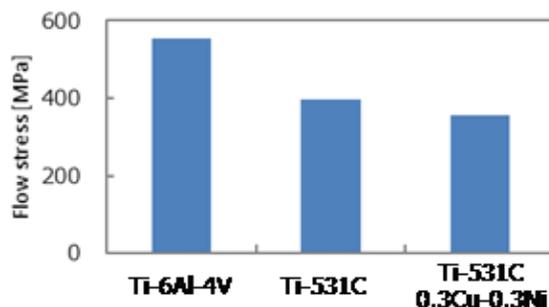


Fig. 5 Flow stress of alloys at 50% compression ratio.

Fig. 6 shows the maximum width of wear on the flank face of the tool after machined 20 m in machining tests. Amount of tool wear decreased with Cu and Ni addition in the range of 0.1 to 1.0 mass%, however, the amount of wear increased with 2.0 mass% addition. Microstructures of workpieces are shown in Fig.7. Microstructure of Ti-531C alloy with Cu and Ni addition in the range of 0 to 1% were composed of $\alpha + \beta$ phase. On the other hand, precipitates on α/β grain boundary were observed in addition to the $\alpha + \beta$ phase, with Ti-531C-2Cu-2Ni alloy. In EL-F alloy, it is reported that precipitation of TiC promotes wear of machining tool [7]. In this investigation also, material with precipitation showed higher wear of tool.

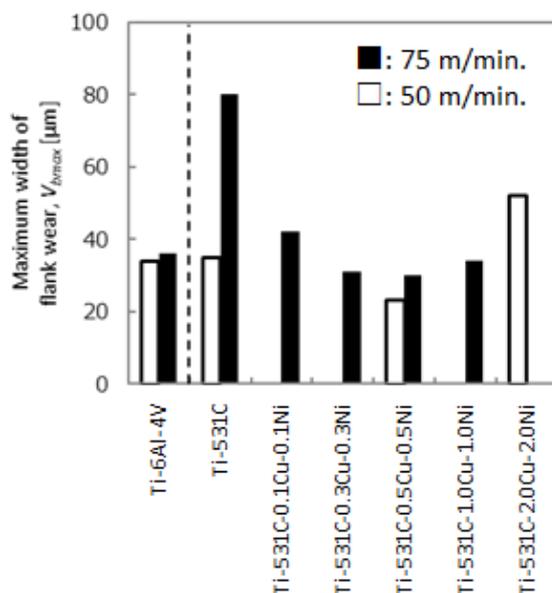


Fig. 6 Maximum width of wear on the flank face of the tool after machined 20 m.

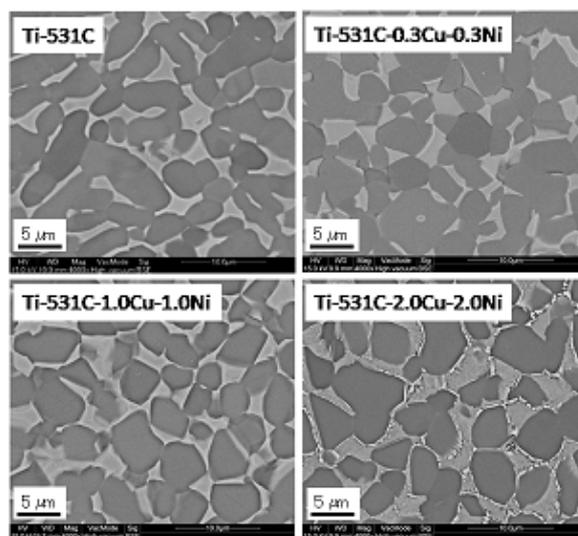


Fig. 7 Microstructures of Ti-531C (n=0 to 2) alloys

Fig. 8 shows SEM photographs of the cutting edge of tools after machining tests. The area shown in dark gray corresponds to TiAlN which is coating material of the tool. The area shown in bright gray corresponds to titanium, which indicates that material of workpiece adhered to the tool at this area. The area shown in white corresponds to WC-Co, which indicates that coating material of tool was lost and WC-Co matrix of tool was exposed at this area. It was suggested that Cu and Ni added material had less adhesion of titanium to the tool and a reaction between the tool and workpiece was suppressed.

It is known that dispersion of low strength or low melting point precipitates in materials could lead to improvement of machinability [8]. On the other hand, dispersion of precipitates in this alloy did not lead to the improvement of machinability. In another aspect, it is necessary to suppress excessive chemical reaction between the cutting tool and the workpiece to improve machinability [9]. Titanium materials are known as an active metal. New surface which appears just after removed previous surface is easy to react with other substances particularly. In machining test of materials with Cu and Ni addition, reduction in the amount of adhesion to the tool was observed. It suggests that the reaction between tool and workpiece was suppressed, however, the mechanism of it is not clear.

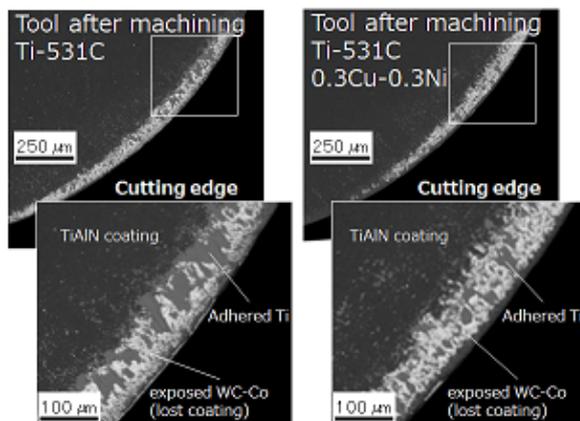


Fig. 8 SEM photographs of the cutting edge of tools after machining tests

Fig. 9 shows the evaluation results of the maximum wear on the flank face of the tool with cutting length up to 90m. In the case of Ti-64 alloy, increasing rate and amount of wear were small up to a cutting length of about 40 m, and wear progressed rapidly from the cutting length of 50 m. On the other hand, in the case of Ti-531C-0.3Cu-0.3Ni alloy, increasing rate and amount of wear were small until the cutting length reached about 80 m, and thereafter wear progressed rapidly. Machinable length without rapid wear was extended in Ti-531C-0.3Cu-0.3Ni alloy compared to Ti-64 alloy, however, after rapid wear occurred, the amount of wear exceeded the allowable range rapidly with any of the alloys. Assuming that the maximum allowable flank wear amount is 150 μm, tool life is extended about 1.5 times in machining of Ti-531C-0.3Cu-0.3Ni alloy compared to that of Ti-64 alloy.

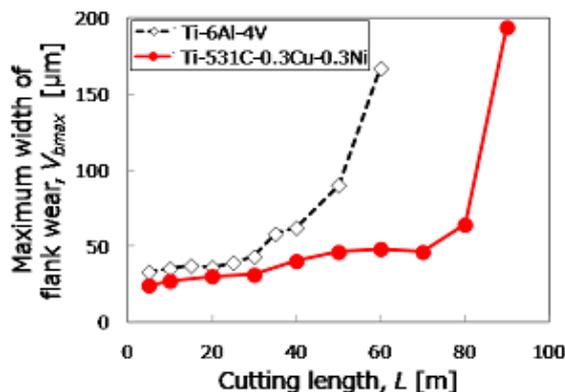


Fig. 9 The maximum wear on the flank face of the tool.

Fig. 10 shows the evaluation results in turning, which is continuous cutting. Cutting depth was 1.5 mm and condition was wet. Cutting speed, feed and coating of tool are shown in Fig. 10. Compared square mark with triangle mark, the amount of removal per unit time is same, and square mark shows lower cutting speed and larger feed. Under the conditions of low cutting speed and large feed, wear amount of any materials was small, and that of Ti-531C-0.3Cu-0.3Ni alloy is smaller. On the other hand, with non-coated cutting tools, large wear occurred immediately in both materials. In the case of continuous cutting, the edge temperature of the tool tends to be higher and when amount of wear increases, the area where the edge contacts workpiece increases. As a result, it is considered that reaction between tool and workpiece tends to occur more easily. In the condition in which reactivity become high, wear was rapidly advancing in both materials. These results mean that materials of the tool can affect machinability [10].

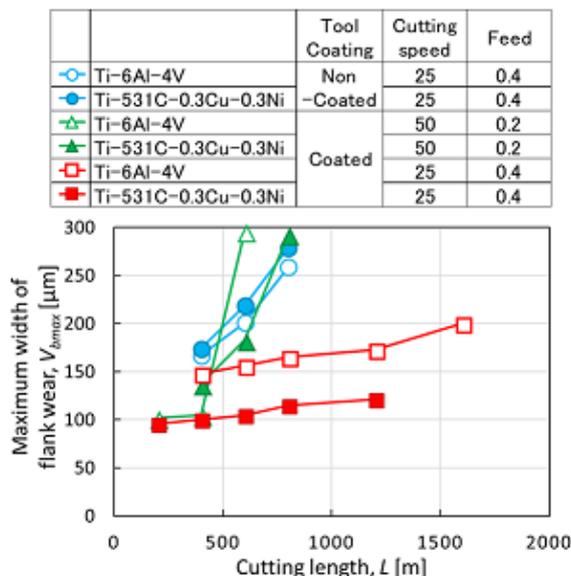


Fig. 10 The maximum wear on the flank face of the tool in turning process.

4. Conclusions

To develop a new alpha-beta type titanium alloy which has good hot forgeability, machinability and mechanical properties equivalent to those of Ti-64 alloy at room temperature, Ti-4.5Al-2.5Cr-1.2Fe-0.1C-nCu-nNi (n=0 to 2) were prepared and evaluated.

The new alloy Ti-4.5Al-2.5Cr-1.2Fe-0.1C-0.3Cu-0.3Ni showed tensile properties equivalent to that of Ti-64 alloy at room temperature. On the other hand, the hot deformation stress of new alloy was about 30% lower than that of Ti-64 alloy, and the excellent deformability was confirmed. It suggests that the new alloy has good forgeability.

The addition of Cu and Ni to Ti-531C alloy suppressed the amount of wear of tool and improved the machinability. Tool life of new alloy machining is extended by about 1.5 times compared to that of Ti-64 alloy. Addition of Cu and Ni is considered to reduce the reactivity between tool and workpiece and improve machinability. However, at conditions where the reactivity become high, this effect seems to be lost.

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