New Developed Ti-10 Zr Alloy for Consumer Goods Application

by

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Synopsis

New Ti alloy has developed to meet the demands out of emerging applications, such as eye glass frames, wrist watches, etc. The composition of the alloy is Ti-10 mass% Zr. Zr, which is non-toxic element for human body, is selected as additional element to maintain superior bio-compatibility of Ti. Zr addition is effective for grain size refinement. Fine grain, under 10μm, is obtained in the alloy after annealing treatment. The alloy possesses excellent cold workability and improved strength to elongation balance compared to commercially pure Ti due to fine grain. Also, fine grain makes it easier to obtain a smooth surface after polishing treatment. It gives strong advantage for the alloy to consumer goods applications whose appearance is important.

1. Introduction

Recently, new titanium markets have been emerging. These new markets mainly consist of consumer goods and leisure applications, such as eye glass frame and wrist watch, etc.. Especially, the demands in the eye glass frame and the wrist watch are increasing, due to the concern at skin allergy caused by Ni.

Commercially pure titanium has been widely used for these applications. However, high strength materials are required to prevent surface scratch on surface of the products as well as to achieve more sophisticated design. It is difficult for the commercially pure titanium to meet these requirements. Namely, commercially pure titanium, such as JIS grade 1 and 2, are too soft to satisfy the high strength requirement. On the other hand, harder grade, JIS grade 3 and 4, are sometimes difficult to apply for the consumer goods applications because of their poor cold workabilities.

Sumitomo Metal has developed a new titanium alloy, SAT10CF (Ti-10mass%Zr) on the basis of above mentioned backgrounds. This alloy possesses high strength as well as high workability at room temperature to meet the requirements for consumer goods applications.

This paper presents the characteristics and properties of the alloy.

2. Alloy Design Concepts

Zirconium (Zr) is selected for additional element to achieve high strength on the basis of four reasons as follows. Aimed strength is the same level of nickel silver alloy, which is the conventional alloy for eye glass frame applications.

(1) Tendency of Zr segregation is very small during solidification. Homogeneity of the chemical composition can be easily obtained throughout an ingot after conventional vacuum arc remelting (VAR) process.

(2) It is necessary not to add toxic element such as Ni, to prevent skin allergy. This point is very important in development of the material for the consumer goods applications such as wrist watches. Zr, as well as Ti, is known as a non-toxic element for human body. Therefore, Zr is one of attractive additional element to maintain bio-compatibility of titanium alloy.

(3) There is no solubility limit for Zr in Ti matrix. Therefore, no embrittlement takes place by formation of intermetalic compound. This is important to maintain high cold workabilities as well as high

strength.

(4) Addition of Zr is effective to refine microstructure of the alloy. **Figure 1** shows the effect of Zr addition on the grain size after annealing treatment at 973K for 3.6ks. Fine grain size under 10μm is achieved by the addition of Zr equal and more than 5 mass%. Retarded diffusion coefficient by Zr addition should be responsible for the grain refinement. Fine grain makes it possible to possess high strength, high workability as well as excellent polishabilty as mentioned later.

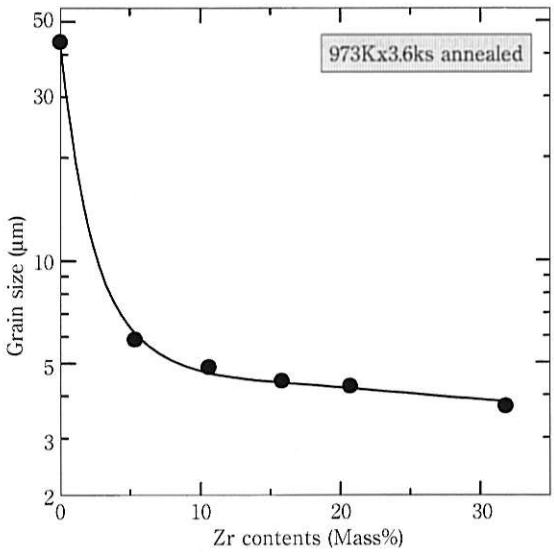


Fig. 1 Effect of Zr content on grain size after annealing

3. Determination of Chemical Composition

Figure 2 shows the effect of Zr addition on longitudinal tensile properties after annealed sheet at 973K for 3.6ks. Tensile strength is around 550N/mm² by addition of 10mass%Zr, which is equivalent strength of conventional nickel silver alloy. Therefore, Zr content is determined to be 10mass% Zr to satisfy the high strength requirement.

Table 1 shows chemical composition of the alloy. As for impurity elements, oxygen content is controlled below 0.10 mass% not to deteriorate cold workabilities. Also, iron content is controlled to prevent the formation of intermetalic compound, TiFe.

Table 1 Chemical composition of the SAT10CF alloy

mass %

Zr	Fe	O	N	C	H	Ti
9.0-11.0	≦0.15	0.03-0.07	≦0.02	≦0.05	≦0.013	Bal.

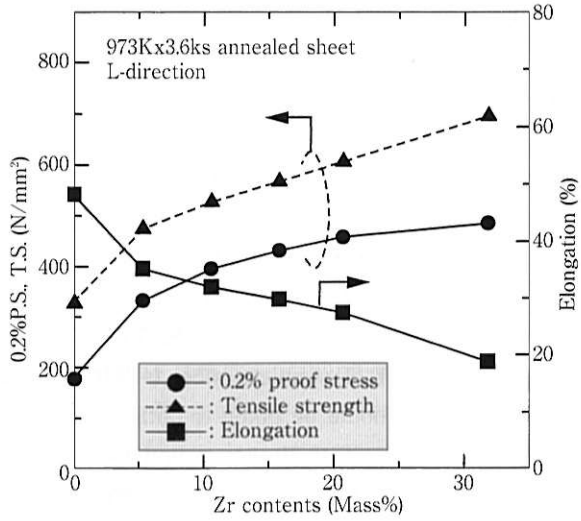
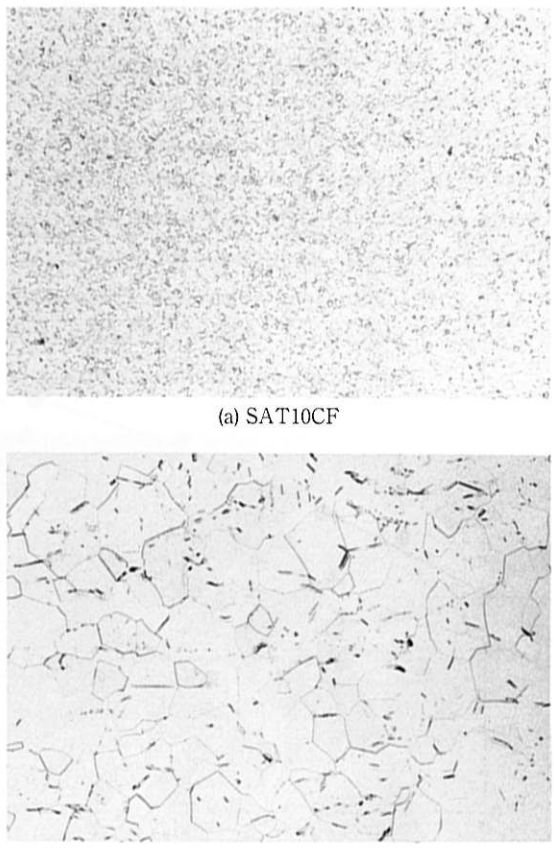


Fig. 2 Effect of Zr content on tensile properties after annealing

4. Properties of Ti-10mass% Zr Alloy (SAT10CF)

Photo 1 shows microstructure of SAT10CF alloy after annealing treatment at 973K for 3.6ks in comparison with that of commercially pure titanium. Fine microstructure is obtained as predicted by **Fig. 1**.



(a) SAT10CF

(b) C.P.Ti (JIS Grade2) 100μm

Photo 1 Microstructure of the SAT10CF alloy and commercially pure titanium (JIS Grade 2)

Table 2 shows physical properties of SAT10CF alloy, commercially pure titanium and Nickel silver alloy. Nickel silver alloy is conventional alloy for eyeglass frame application. There are no differences in specific gravity and young's modulus between the SAT10CF and commercially pure titanium. On the other hand, small specific gravity, compared to Ni silver alloy, is beneficial to weight reduction of the products. Young's modulus of the SAT10CF alloy is smaller than that of stainless steel (=21000N/mm^2). Therefore, care should be taken to obtain the desired precision of the SAT10CF alloy products shape, due to a large amount of spring back after forming operation.

Figure 3 shows the effect of cold working on tensile properties. Tensile strength of the SAT10CF alloy is higher by about 20% than that of the commercially pure titanium, grade 2. The alloy can be cold rolled up to 90% without intermediate annealing. Also, there is no reduction in ductility by cold rolling. It can be judged that the SAT10CF alloy possesses excellent cold workability. **Figure 4** shows tensile strength and elongation balance of the annealed SAT 10CF alloy sheet in comparison with those of commercially pure titanium, grade 2 to grade 4. It is seen that the SAT10CF alloy possesses better tensile strength and elongation balance than the commercially pure titaniums. This improvement in the balance can satisfy the requirements of new applications, to which commercially pure titanium is difficult to apply. Fine microstructure contributes to the improvement in the cold workability and tensile strength/elongation balance.

Besides mechanical properties as mentioned above, it is required to possess high polishability for the material for consumer goods applications. As titanium is susceptible to surface scratch, it is difficult to obtain shiny surface on the products. That is, polishability of titanium is poor, in general. Fine microstructure of the SAT10CF is very effective for the improvement in the polishability. **Figure 5** shows surface roughness after polished by a certain condition. It is obvious that smooth surface is obtained in the SAT10CF alloy in comparison with commercially pure titanium

Table 2 Physical properties of the SAT10CF alloy

	SAT10CF	CPTi	Nickel Silver
Specific gravity	4.6	4.5	8.5
Thermal expansion coefficient (1/K)	9.3x10^{-6}	8.4x10^{-6}	20x10^{-6}
Young's modulus (N/mm^2)	106x10^3	104x10^3	95x10^3
β transus (K)	1123	1183	-

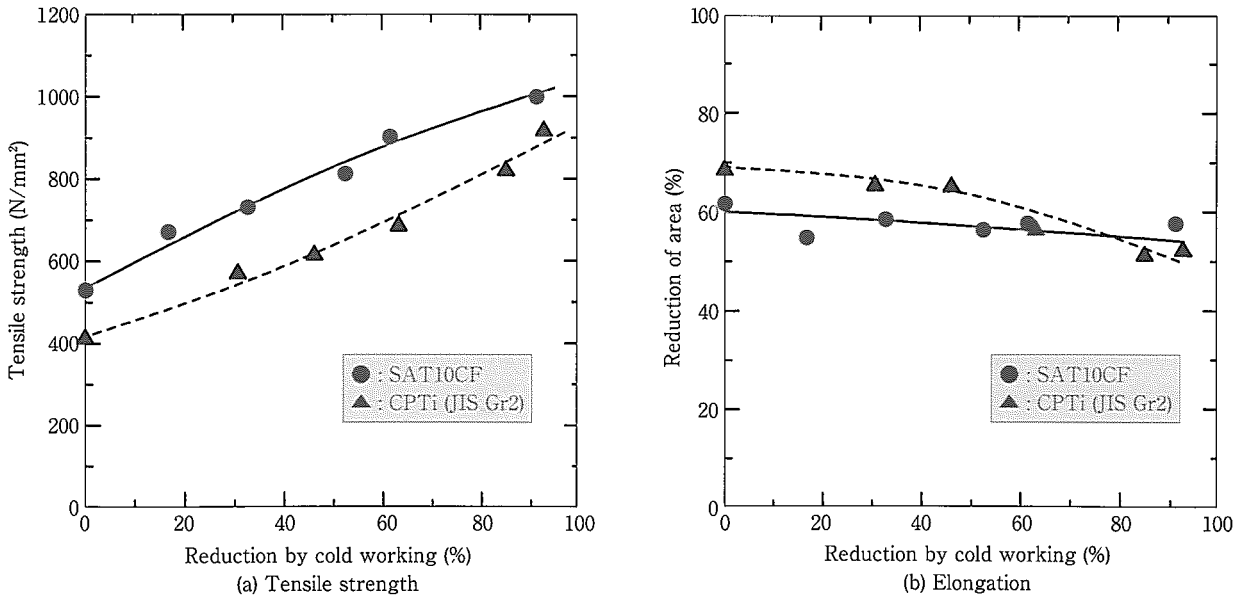


Fig. 3 Effect of cold working on tensile properties, as rolled condition

and beta titanium alloy. This high polishability has strong advantage to the consumer goods applications such as eye glass frame of which external appearance is very important.

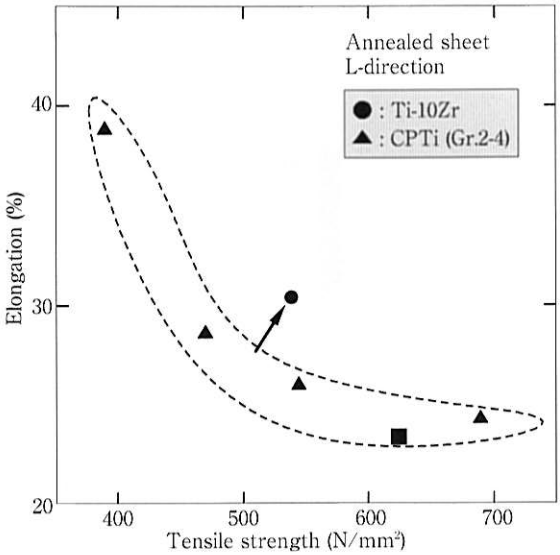


Fig. 4 Tensile strength and elongation balance of the SAT10CF alloy and commercially pure titanium (JIS Grade2-4)

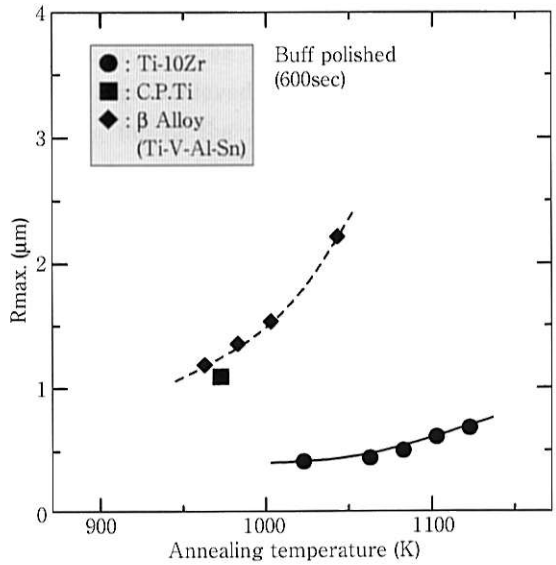


Fig. 5 Surface roughness after buff polishing for 600s

5. Manufacturing of the SAT10CF Alloy

The SAT10CF alloy can be manufactured by conventional process for titanium products. Ingot, melted and cast by VAR process, is rough forged to make billet, followed by hot rolling and cold rolling to sheets and coils. Cold rolled and annealed coil, 1mm or under in thickness with 1m wide, is successfully manufactured by using of the conventional process for commercially pure titanium. These products are used for the wrist watch materials.

As for wire, surface of hot rolled coils are peeled off to remove oxide layer, followed by cold rolling. Conventional manufacturing process for wire is drawing. However, manufacture of the titanium wire by the drawing process is very difficult, because titanium easily stick to surface of the drawing tool. On this point, Sumitomo Metal has developed a special wire cold rolling mill for titanium and other special metals. The mill consists of a series of housings equipped with four rolls. The material is continuously rolled by the housings at high speed with accurate dimension and good surface condition. The SAT10CF alloy wires, 1.6 mm in diameter or less, is successfully manufactured by this cold rolling mill. These wires are mainly used for eye glass frame materials.

6. Applications of the SAT10CF Alloy

The SAT10CF alloy is used for eye glass frames and wrist watch materials. **Photo 2** shows an eye-glass frame made by the SAT10CF alloy.

Titanium is widely used for eye glass frame materials by taking advantage of its light weight property, especially in Japan. On the other hand, the concern for skin allergy is mounting on a global scale. As titanium is immune to skin allergy, attention has been attracted to titanium for the applications which contact human body. The SAT10CF alloy is attractive material for these applications. Also, the SAT10CF alloy is hoped to pioneer new applications by taking advantage of its excellent mechanical properties, high polishability and high bio-compatibility.

Photo 2 Eye glass frame made by the SAT10CF alloy

7. Summary

The new developed titanium alloy, the SAT10CF alloy is presented. The alloy consists of Ti-10mass% Zr. Key concepts of alloy design on properties are high strength while maintaining workability and biocompatibility. Fine grain structure is obtained by the addition of Zr into titanium. Fine microstructure contributes to improve in mechanical properties as well as smoother surface after polishing process. Products of various forms are successfully manufactured by using of the conventional titanium processes. Main applications of the SAT10CF alloy are eyeglass frames and wrist watch materials.

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References

1) K. Nakasuji and M. Okada : Material : Materials Science and Engineering, A213 (1996). p.162
2) A. Kuroda and W. Takahashi : Proceedings of 1996 International Titanium Application Conference (1996). p.157. International Titanium Association.