Effect of different microstructure on dynamical stab-resistant property of TA15 alloy

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Abstract. The effects of different microstructure on the dynamical stab-resistant property of TA15 alloy are investigated. The specimens were tested on the stab apparatus after heat treatment at temperature of 850, 930 and 1030°C, time of 30min and air cooled. The impact force-time curves, microstructure and fracture morphology of specimens were analyzed. The results showed that the properties of higher strength and plasticity are benefit to the performance of stab resistance of TA15 specimens, and the curves of 930°C and 850°C exhibit two peaks and longer time ranges, but the curve of 1030°C exhibits the shortest time to reach the peak of impact force, and the specimens heat treated at 850°C exhibit the better performance against the knife impactor because of fine grain and stronger grain boundary binding force to absorb the impact force energy.

Keywords: TA15 alloy, stab-resistant, microstructure, impact force

1. Introduction

For better performance of impact resistance property, a sandwich structure which consists of metal, fiber, and other soft materials [1] has been used as the energy absorption component in protection system in recent years. It has the property of high specific stiffness, low specific mass and high energy absorption. In the sandwich structure, the correct choice of metal plate is very important to the stab-resistant property with weight reduction and protection level improvement.

There are a lot of research on sandwich structure which using ceramic layer [2-3], aluminum layer [4-5] and polyethylene reinforced by Waterborne Polyurethane Resin or polymeric resin [6-7] to enhance the strength of the composite structure. According to the past several years research on sandwich structure, It can be known that high strength and lightweight properties is important to the stab-resistant performance. But there are few researches are available to study the stab-resistant performance of titanium which used as the strength and stiffness layer of the sandwich structure.

Titanium alloy has widely applied to many fields because of its excellent mechanical properties, low density and high specific strength [8-9]. It can be used as the high specific strength and stiffness layer to stop penetration by sharp point and cutting by blade edge effectively. TA15 (Ti-6.5Al-2Zr-1Mo-1V) alloy has been used as load-bearing structure in aerospace industry due to their excellent mechanical and physical properties [10-11]. In this research, The effect of different microstructure on stab resisting properties and energy absorption of TA15 titanium alloy was tested and analyzed.

2. Materials and experimental methods

2.1. Materials

The chemical composition of TA15 titanium alloy used in this work is Ti-6.5Al-2Zr-1Mo-1V(wt%). The testing specimens from TA15 sheet with 0.5mm thick were machined into square with 25mm in width and
length for stabbing test. The initial microstructure of the samples consists of about 85% α phase and a few of β phase, as shown in Fig.1. In order to understand the effect of different microstructure on stab-resistant performance of TA15 alloy, the specimens were heat treatment at temperature of 850, 930 and 1030℃, time of 30min and air cooled to provide different microstructure.

**Figure 1.** The initial microstructure of TA15 alloy.

### Experimental apparatus

The stab-resistant properties of TA15 alloy with different microstructure were tested on the apparatus that drops freely under its own weight to strike the targets at a specified energy, which consists of an engineered knife blade on the drop mass. In the test, TA15 alloy specimen is 16 cm×16 cm in size, and the data of energy and displacement during the process of stab was recorded by the sensors connected with computer. The apparatus are shown in Fig.2.

**Figure 2.** Schematic and instrument for dynamic stab test.

The tests specimens were divided into 2 groups according to the stab way. Group 1 was stabbed by knife directly on the circular jaws of the instrument, and group 2 was stabbed by knife with placing specimens on the rubber which is a simulation of human body. The circular jaws having inner and outer diameters of 72 mm and 105 mm, respectively. The apparatus that drops freely under its own weight to strike the specimens at a specified energy. The impactor is S1 knife based on NIJ Standard NIJ Standard–0115.00[12] as shown in Fig.2. The knife impacted the titanium sheet specimens at a speed of free falling movement, and the drop height was set 0.52 m for each specimen and the weight of knife was 2.33 kg. After test of stab, the microstructure and the crack section of TA15 alloy were observed by OM and SEM and the energy data were analyzed.

### Results and discussion

#### 3.1. Relationship between stab-resistance and Mechanical properties of TA15 alloy

For titanium alloy, there are more research about the use of aerospace, but other use of which is seldom to be observed. In order to understand the relationship among the property of stab-resistance, strength and
plasticity, the mechanical properties of 0.5 mm TA15 alloy sheet with different heat treatment are shown in Fig.3. It can be seen that with the increasing of heat treatment temperature, the plasticity of TA15 alloy is decreasing, the strength is reduced apparently at 1030°C.

Figure 3. Mechanical properties of TA15 alloy with different heat treatment (a) strength (b) plasticity.

The drop tower stab performance of the TA15 alloy targets against the knife impactor are shown in Fig.4. The specimen heat treated at 850°C exhibits slightly less penetration crack, and the specimen which heat treated at 1030°C, reach the maximum penetration crack as compared with the other targets at the same energy levels. It can be seen that the specimens which heat treated at 850°C and 930°C show better performance against the knife impactor either in group1 or in group 2, especially the specimen heat treated at 850°C.

Figure 4. Photographs of TA15 alloy specimens: (a) before dynamic stab test, (b) after dynamic stab test against knife impactor on the circular jaws and (c) after dynamic stab test against knife impactor on the rubber simulated as human body.

It is mean that higher strength and plasticity of TA15 specimens are benefit to the performance of stab resistance. In addition, note that the extent of damage is clearly less in the group 2, although penetration occurs in both targets. In the specimen which heat treated at 930°C, the penetration is a small dot as diameter of about 0.2mm and depth of 2mm, but the penetration is a dot as diameter of about 0.4mm and
0.2mm of depth, and the specimen which heat treated at 1030°C is cracked definitely. It can be deduced that the energy of impact is absorbed by the rubber mainly and the high strength of TA15 specimens is used to resist the strength of stab. So the high strength layer which in the upper or middle location to stab impactor would be more effective for stab resistance than which in bottom in sandwich structure.

3.2. Relationship between property of stab-resistance and microstructure of TA15 alloy

Fig. 5(a) shows the impact force of TA15 alloy specimens against knife impactor during the dynamic stab test on the circular jaws and at the drop height of 0.52 m. It can be seen that all the curves exhibit the peak of impact force, and the curves of 930°C and 850°C exhibit two peaks, but the time ranges are different for specimens with different heat treatment temperature. It is related with the different way of energy absorption during stab resistance. The gradient of impact force and time at the increasing curve shows the process of energy absorption during penetration of stab, and the peak of impact force indicate the amount of energy absorbed by specimens before penetration, lastly the time range of curve reveal the ability of stab resistance for specimen. As can be seen in the Fig.5(a), the curve of 1030°C exhibits the shortest time of about 0.3ms to reach the peak of impact force, and the peak of impact force is 2.55KN when the specimen penetrated. Compared with other specimens, it is also mean the poor performance of stab resistance for specimen heat treated at 1030°C. The curves of 930°C and 850°C exhibit longer time range, show the relatively large amount of energy absorbed and gradually reach the peak of impact force, especially the curve of 850°C. The specimen heat treated at 850°C exhibits the better performance against the knife impactor as proved in Fig.5.

**Figure 5.** Dynamic stab test of TA15 alloy specimens against knife impactor: (a) on the circular jaws, (b) on the rubber simulated as human body.

In order to analyze the damage mechanisms in the TA15 alloy specimens, the OM and SEM images of TA15 alloy specimens tested against the knife impactor under drop tower conditions are shown in Fig.6.

**Figure 6.** The microstructure nearby the penetration and fracture of TA15 alloy specimens which heat treated at different temperature after dynamic stab test. (a)(e) 850°C, (b)(f) 930°C, (c)(g) 1030°C.
The regions of crack extension in the direction of thickness in specimens are observed by OM, and the fractures are observed by SEM. For the microstructure of TA15 alloy heat treated at 850°C, the extended region of the penetration crack is discontinuous (the region circled by white in Fig. 6a) and the fracture is consisted with large amount of fine dimples (in Fig. 6e). It is indicated that crack extension occurred in the specimen after the relatively long process of plastic deformation accumulating to some degree. In Fig. 6b, the specimen heat treated at 930°C experiences extended crack continuously and large dimples can be seen in fracture as shown in Fig. 6f, which reveals that the crack resistance of specimen is related with plastic deformation. Lastly, the SEM photograph of specimen heat treated at 1030°C show brittle fracture, and the typical intergranular fracture induced by the stress concentration from the directed contact with the tip of the knife impactor can be observed in Fig. 6g.

As mention above, it is obvious that the performance of TA15 alloy during the dynamic stab test against knife threat can be effectively improved by controlling the microstructure, and the specimens with fine grains show stronger capability to absorb the impact force by grain boundary binding force strongly.

4. Conclusions
The dynamic stab resistance properties of TA15 alloy with different microstructure against knife threats were studied in this paper. The relationship between impact force-time curve and mechanical properties show that the properties of higher strength and plasticity are benefit to the performance of stab resistance of TA15 specimens. All the curves of dynamic stab resistance during stab test exhibit the peak of impact force, and the curves of 930°C and 850°C exhibit two peaks and longer time ranges, but the curve of 1030°C exhibits the shortest time to reach the peak of impact force. The research of microstructure and fracture morphology of TA15 alloy with different heat treatment indicate that the specimens heat treated at 850°C exhibit the better performance against the knife impactor because of fine grain and stronger grain boundary binding force to absorb the impact force energy.

5. References
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