GRAIN BOUNDARY SLIDING IN SUPERPLASTICITY FORMING of TITANIUM ALLOYS (Ti6Al4V)

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Abstract : *The major property of super plastic material is the high strain rate sensitivity (m ≥ 0.3), which provides high resistance to necking growth, the extension can be obtained is very high (e> 500%) without breaking. decent to obtain high m, the material requirements must have been a fine grain size, where the grain size (d≤ 10µm) is equal-axial or round and stable at high deformation temperatures.Grain boundary sliding is a process in grains slide passing each other, or in the zone directly adjacent to, their common boundary In-situ observation of grain boundary sliding using electron microscopy. The material must be fine-grained, because at super plastic at high temperatures the main deformation mechanism is "Grain Boundary Sliding", Rounded (equal) grain fo where finer grains in the wider plane the sliding plane becomes easier to slide. Large-angle grain boundaries will facilitate sliding. In addition, grain boundaries must be easy to move to avoid local stress concentrations. In super plastic deformation the grain remains equal axial after under large deformation, a proof that grain boundary migration occurs. It should be also pointed out that grain boundary sliding has been considered a dominant deformation mechanism in super plasticity, although the term super plasticity does not simply or even define a particular deformation, mechanism, there is a general agreement that grain boundary sliding contributes more than 50% of the total strain in super plastic material.*

Key word: Super plastic, Titanium alloys, Equal , Sliding, Deformation, grain boundary

INTRODUCTION

1.1 Fundamental

Technological in recent years developments was increasing rapidly, the complexity of components or products, especially in aircraft structures, it is necessary to find an advanced manufacturing method to fulfill materials needs. In a complex product, if its formed conventionally where machining and forming needs several stages of process and wasted material, and the processes which can be make complex products in one stage in the process will save costs and materials. The super plasticity forming is one alternative that able to answer the above problems, especially for "sheet metal material".

Super plastic is a metal forming process that is capable of producing products with the large plastic deformations (500-1300%). Several factors influence super plastic deformation research is needed to be studied further more especially in aircraft components that used Ti6AL4V alloys which have high strength, lightweight, and resistant to high temperatures and have high corrosion resistance. Factors influencing super plastic deformation are grain size, it must be small than (<10 µm), stable and equal (material properties) high deformation temperature> 0.5 CT and slow strain rate around 10-5 / s (process stage)

1.2 Scope

In this study mechanism of the boundary sliding and the grain size will be measure and compared before and after super plastic deformation.

1.3 Research goals

This study aims to find changes in the grain size of the super plastic forming process and demonstrate the grain boundary sliding mechanism occurs in the super plasticity process by analyzes the microstructure of the grain.

METHODS

The major property of super plastic material is the high strain rate sensitivity (m ≥ 0.3), that provides high resistance to the necking growth where the extension can be obtained is very high (e> 500%) without breaking. To obtain high m, the material requirements should has a fine grain size, where the grain size (d≤ 10µm) is equal or round and stable at high deformation temperatures. The material must be fine-grained, because super plastic process occur in high temperatures with deformation mechanism named "Grain Boundary Sliding", the fine grains flow extend and the sliding plane will be easily sliding. Equi-axial grain form, and large-angle grain boundaries will facilitate sliding. Grain boundaries also must be easy to move to avoid local stress concentrations. In super plastic deformation, the grain remains equal-axial after go through large deformation, a evidence the grain boundary migration be held.

For grains to remain smooth (stable) at deformation temperatures, in other words, to prevent grain growth at high deformation temperatures, super plastic materials must have two or more phases with a balanced ratio of volume phase fractions (micro duplex material) or single-phase material with an amount small subtle second phases are spread evenly over the grain (Pseudo-single phase material) which inhibits the growth of grains at high temperatures, because the second phase acts as a stabilizer of grain boundaries. Generally, super plastic alloys have eutectic or eutectoid compositions.

The fine grain structure of super plastic material, generally achieved by several methods or a combination. Methods for smoothing grains that are commonly known include:

- Phase transformation method
- Re-crystallization method
- Inhomogeneous deformation of duplex alloys methods
- Phase separation method in duplex Alloys

The first and the second methods, phase transformation and re-crystallization, the aim is to form a grain core within each grain of the parent microstructure. In the third method, the two-phase duplex alloy deformation is broken and discredited. Deformation is usually accompanied by re-crystallization in the second phase which contributes to the refinement of the whole grain. In the fourth method, the initial microstructure is not a stable duplex microstructure but is generally martensite or a saturated solid solution. Separation of phases from stable structures if its altered by two stable phases can produce fine-grained duplex microstructure. Figure below shows how grain boundary sliding in shear and tensile stress.

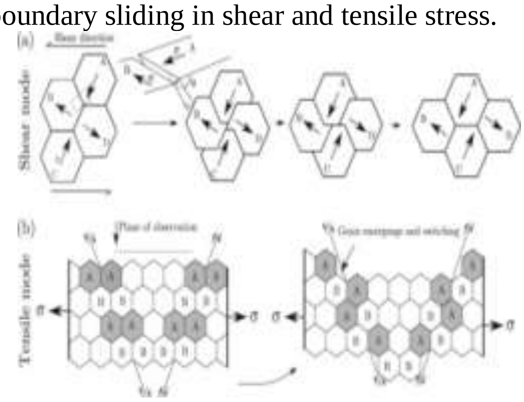

Fig.1 (a) grain boundary sliding in shear stress. (b) grain sliding in tensile stress.

2.1 Super Plastic Process

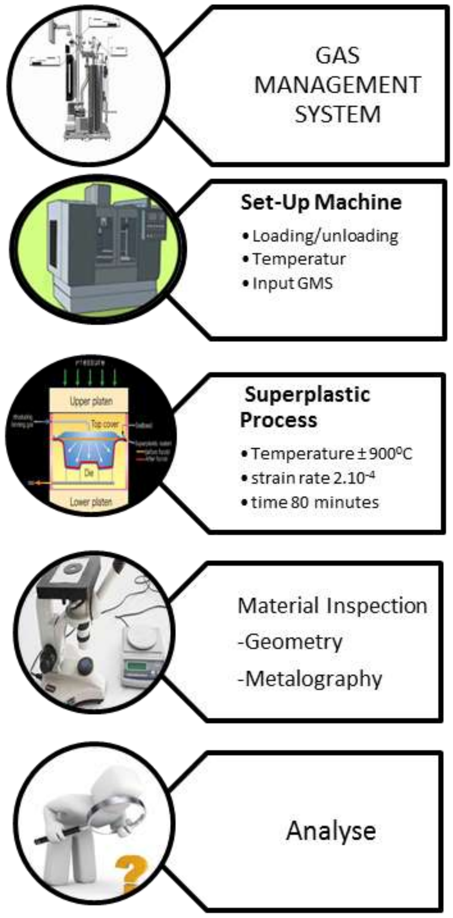

Fig. 2 Procedure of Super Plastic Process

Super plastic is a phenomenon that material can achieve large elongation (hundreds or even up to thousands of percent). It is occur because the material has a high resistance to necking (local cross-section reduction). The Necking possible to occur because the super plastic material has a m (sensitivity high strain rate), and also this is achieved for certain process conditions the process takes place at high temperatures and low strain rates. Flow stress equation at high temperature is expressed in flow stress which is a function of strain rate and temperature. If the temperature in the specimen can be considered uniform then only the strain rate will affect the flow stress, as stated in the following process.

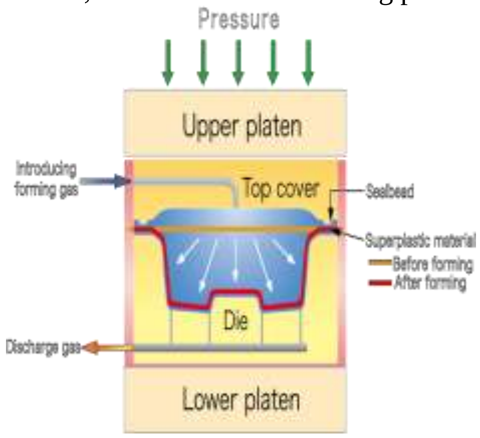

Fig.3 Mechanism of super plastic forming

If the temperature in the specimen considered to uniform and only strain rate will affect to the flow stress as following equation:

$\sigma_0 = C. \acute{\varepsilon}^{m}$ ……………….. (1)

m = strain rate sensitivity

$\acute{\varepsilon}$= strain rate

c = Constanta

It can be explain that super plastic is "intentional creep" because the deformation mechanism in super plastic is "similar" to the creep mechanism. The main creep mechanism can be grouped as follows:

1. Dislocation glide involves dislocation movement along with the slip plane and passing barriers by thermal activation. This mechanism occurs at high strain.

2. Creep dislocation, including the movement of dislocations that can exceed obstacles by thermal mechanisms through the diffusion of emptiness or interstitial.

3. Diffusion creep involves the flow of emptiness and interpretation through the Crystal under external influences.

4. Grain boundary sliding (grain boundary sliding), including the shift from other grains. Of the four creep mechanisms above, only the dislocation launch (glide dislocation) does not occur at super plastic because the super plastic stress occurs low.

2.2 Material

The Ti-6AL-4V alloy has the following chemical composition

Table1. Chemical Composition of Titanium Alloys

Element	Percentage (%)
Al	6.0775
V	4.0325
Si	0.0615
Fe	0.02386
Mo	0.0207
Mn	0.0121

Each element has each element has an important function in the micro structure:

elements	**Range Wt %**	**Influenced on structures**
Aluminum	2-7	α Stabilizer
Tin	2-6	α Stabilizer
Vanadium	2-20	β Stabilizer
Chromium	2-12	β Stabilizer
Molybdenum	2-20	β Stabilizer
Copper	2-6	β Stabilizer
Zirconium	2-8	booster α dan β
Silicon	2-1	Increase creep resistance

The application of this material is in aircraft structure, turbine components, gas and other uses. The phase diagram is as follows:

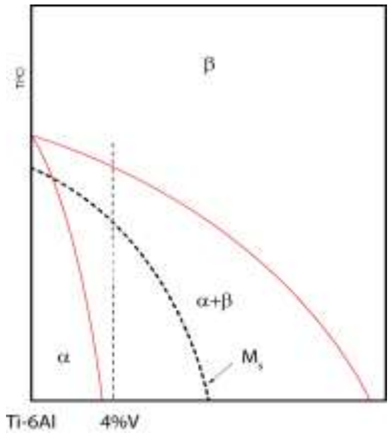

Fig.4 Phase diagram of Titanium alloys

The reviewed from the liquid temperature of Ti6AL4V 1668^0C, the conditions of the super plastic deformation process for Ti6AL4V> 688^0C (1.2 Tm), and seeing at the phase diagram, the selection of the super plastic deformation process temperature is such the volume fraction of α and β is balanced so that the seed growth is completely really stopped. This temperature is around 875-950^0C, where the strain rate ranges from 10-5 - 10-3/sec.

The properties of Ti6AL4V in room temperature are as follows:

1. Species density = 4,428 g / cm3
2. Liquid temperature = 1992 K
3. Thermal conductivity = 3,069 W / m. k
4. Specific Heat = 564 J / Kg. k
5. Tensile Strength = 896 M.pa
6. Yield Strength = 827 M.pa
7. Extension = 10%
8. Modulus of elasticity = $11.3.10^4$M.pa
9. Hardness = 36 RC

The features of the Ti6AL4V alloy are as follows:

1. High strength
2. Resistant to high and low temperatures
3. Able to super plastic properties
4. Corrosion resistant
5. Able to hardness by heat treatment or a Mechanics thermal process

RESULT AND ANALYSE

The main material requirement for the super plastic process is the material must be fine-grained, because at super plastic at high temperatures the main deformation mechanism is "Grain Boundary Sliding", with fine grains the sliding area will be wider, and sliding more easily. Rounded form (equal-axial) grain form, large-angle grain boundaries will facilitate sliding. Grain boundaries must be easy to move to avoid local stress concentrations. In super plastic deformation the grain remains equal-axial after ongoing a large deformation, a proof that grain boundary migration occurs. In the microstructure photo above it can conclude that there is almost no change in the grain size of the initial material and the material resulting from the super plastic process which has lead a deformation of 225%, the grains only sliding during the super plastic formation process.

Fig. 5 microstructure before super plastic forming

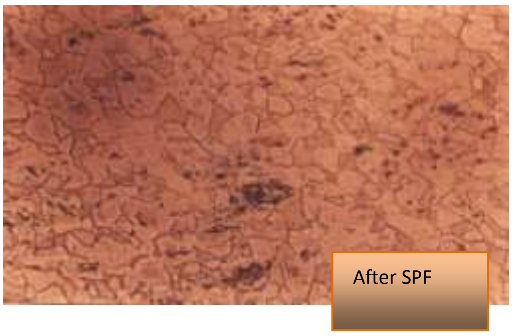

Fig. 6 microstructure after super plastic forming

The amount of deformation that occurs can be said to be very large and cannot be carried out on other materials, because usually after serve deformation the grain structure will usually get bigger and the shape will be flattened, but on Ti6AL4V material it does not occur, because during the deformation process the grain structure occurs deformation only migrates by sliding which are causes the deformation that occurs more large. It is difficult for grains to change shape where the local crossing (necking) can be delayed. From Figure below can be seen how the grain boundary sliding process occurs in the super plastic forming process.

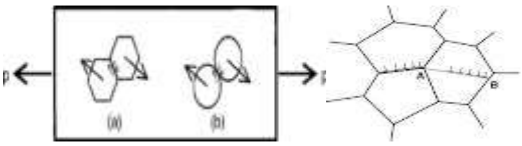

Fig 6. Mechanisms of grain boundary sliding during super plastic flow.

This analysis can be seeing that "sliding grain boundary" mechanism indeed occurs in the SPF process. If seen based on Figure 4, the liquid temperature of Ti6AL4V 1668^0C, the conditions of the super plastic deformation process for Ti6AL4V> 688^0C (1.2 Tm), the selection of the temperature of the super plastic deformation process is such as the volume of the α and β fractions are balanced and the super plastic deformation conditions for Ti6AL4V> 688^0C (1.2 Tm) for Ti6AL4V> 688^0C (1.2 Tm) is completely blocked.

CONCLUSION

The "grain boundary slide" mechanism can occur by selecting the right material with a balanced composition of the volume fraction α and β, and the right temperature range setting, it between $875\text{-}950^0$C and the deformation no more than 10-5 - 10-3/sec.

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