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ASTM E2448—A Unified Test for Determining SPF Properties

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The determination of the superplastic properties of a material, just like any mechanical property, is highly dependent on the test method, coupon geometry, and analysis of the raw data from the test. Thus the published properties of a material from one source will differ from that of another source unless a common test method is employed. The ASTM E2448 Standard Test Method for Determining the Superplastic Properties of Metallic Sheet Materials has been written to provide a common platform for testing, evaluating, and publishing superplastic properties to a uniform format, useful for both academia and industry. The Boeing Company is now using ASTM 2448 to quantify the superplastic properties of fine grain Ti-6Al-4V alloy, and is specifying it to qualify production material to the Boeing Material Standard BMS7-385. The standard includes specimen geometry and testing conditions, the test machine requirements, and how to analyze the data, including the basic stress vs. strain curve and determination of '*m*' value.

Keywords ASTM, constant strain rate, E2448 standard method, '*m*' value, true strain

1. Introduction

The aerospace industry has been superplastically forming titanium parts since the early 1970s, mostly using sheet metal Ti-6Al-4V alloy. During that period, none of the material was purchased to any superplastic specification, instead it was assumed that the normal manufacturing method used by the titanium producers would naturally produce a sheet material with uniform superplastic properties. There are, of course, variations among manufacturers within gages and heat lots made by any manufacturer. Luckily, the forming process is very tolerant of modest variations; nevertheless, there have been a few occasions when an anomaly in the manufacture of the sheet caused it to have poor superplastic properties, resulting in tearing, non-filling of the die, and failure to form. Even when a part successfully formed, it might have a different thickness distribution across one part compared with another. It is well known that superplastic properties depend, to a large extent, on the grain size, and previously, Ti-6Al-4V sheet material was deemed superplastic if the grain size were 4-8 micron (Ref 1). With the advent of 'fine grain' titanium sheet metal alloys, we, at Boeing have discovered that not only is the grain size more difficult to measure, (it requires an SEM due to the sub micron sizes), but grain size per se is not the only requisite for good superplastic properties. Other factors also affect its performance. Therefore, proper identification and documentation of the superplastic properties of any heat lot is important to the success of the implementation of fine grain titanium on the aircraft. Accordingly, Boeing have specified that an Superplasticity and Superplastic Forming (SPF) test using the ASTM E2448 shall be used to qualify all incoming fine grain titanium for superplastic forming.

2. Scope of the Standard

When forming an SPF part the stress is bi-axial, and ideally this is what should be tested, however the equipment for performing a bi-axial test is complex, especially for testing at the high temperatures required for materials such as titanium and steels. Furthermore, it is not easy to extract the basic SPF properties of the material by this method. Therefore, the more fundamental uni-axial test is preferred. It is recommended that tests be performed in both the longitudinal (L) and long transverse (LT) directions to fully characterize the material and determine any anisotropy. The standard applies to sheet metal, with a thickness from 0.5 to 6 mm.

The test method determines both the basic SPF property of stress versus strain for any strain rate, and also the derived property "m," the strain rate sensitivity. It includes effects due to strain hardening or softening in the material. The basic properties of true stress (σ) and true strain (ε) conditions in the material are defined as

$$\sigma = S(1 + e) \quad \text{(Eq 1)}$$

$$\varepsilon = \ln(L/L_0) \quad \text{(Eq 2)}$$

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where S and e are the engineering stress and strain, L and L_0 are the instantaneous and original lengths. S assumes that the coupon maintains a constant cross section during deformation. This is essentially correct for most of the test until an unstable neck appears toward the end. There is a transition zone from the gage section to the clamp section where the cross section is not uniform, and for this reason the coupon is made with a small radius between the two sections. The transition is about 4% of the length. L and L_0 are ideally measured at the ends of the gage length, but this is not practical. The temperature is too high to apply extensometer arms in many cases and the points may indent into the relatively soft superplastic alloy, causing premature necking and affecting the test result. Consequently, the ASTM method clamps the coupon at the shoulders immediately adjacent to the gage section and measures extension externally at the crosshead. The extensometer will record not only the coupon gage elongation, but also the elastic strain, or compliance, of the crosshead and clamp mechanism, so this needs to be taken into account, especially at the start of the test when loads are highest and coupon extension is lowest. To measure compliance, a 6 mm non-SPF coupon should be mounted in the grips and extensometer extension measured under the highest anticipated load. It is further recognized that during the test the upper clamp extension rod will move out of the furnace and contract as it cools, thus distorting the extensometer readings. This contraction is usually small compared with the increasing length of the coupon and can be ignored in most cases.

The test method applies a constant strain rate to the coupon and measures the load required to maintain it. This differs from many SPF tests where a constant velocity is applied at the crosshead. The reason a constant strain rate has been chosen is that the basic properties of σ and ε are readily obtained for any strain rate, whereas they have to be derived from several tests if the constant velocity method was used. In addition, any strain hardening or softening effect is easily seen in a constant strain rate test. All modern test machines are capable of applying a constant strain rate, some are continuously variable while others step up the speed in small increments.

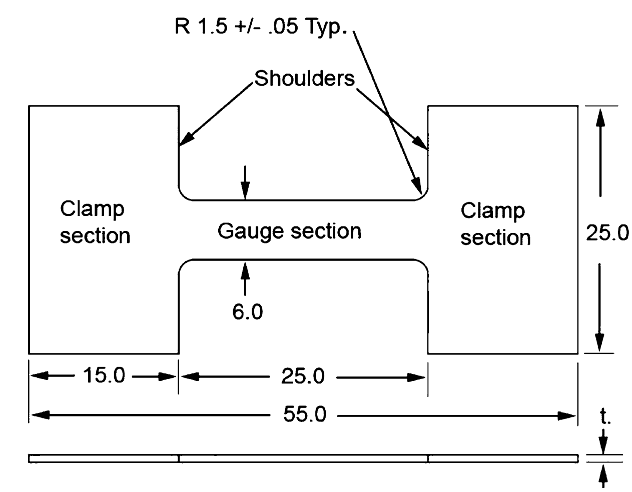

Fig. 1 ASTM standard SPF coupon configuration

3. Coupon Configuration

The coupon shape is shown in Fig. 1. The 15 mm clamp section length is not critical and can be longer. The clamps that hold the coupon are designed to support and load the coupon under the shoulders only, and do not grip it in the clamp section. It has been shown that this technique induces no significant superplastic flow within the clamp section, and the gage section is effectively the distance between the shoulders. Figure 2 shows a typical coupon after 800% superplastic elongation.

4. Clamp Configuration

The design of the clamp is shown in Fig. 3. Each half of the clamp is constructed as a shallow box with an opening in one sidewall, so that the coupon can be placed as shown. The wall opening is 7 mm with a 1.5 mm entry radius. This gives a small clearance around the coupon to ensure there is no frictional load on the gage section as it superplastically forms close to the shoulders. After the coupon is placed in the clamp, a keeper plate is placed over each clamp area and held lightly in place by a bar. Note that the keeper plate does not hold the coupon to the clamp; it is there just to prevent the coupon from falling out. During testing, all the force is transferred from the clamp sidewall to the shoulders of the coupon.

The clamps are attached via extension arms to the base and crosshead of a tensile test machine. This is equipped with a furnace which completely surrounds the coupon and clamps to provide a uniform heat. The furnace must extend a sufficient amount above the top of the upper clamp to accommodate the large movement that the clamp will travel, sometimes more than 200 mm.

5. Test Procedure

The furnace should be preheated to the desired temperature before loading the coupon, to minimize the length of time, the coupon will be exposed to high temperature before the start of the test. After the coupon is loaded, the furnace will need to recover its equilibrium temperature. During this stage, the coupon will elongate due to thermal expansion, and it is important to minimize any external stress imposed by the machine to the coupon. Many modern test machines have a 'protect specimen' or load control' option to accommodate the coupon movement and prevent buckling. It has been found that

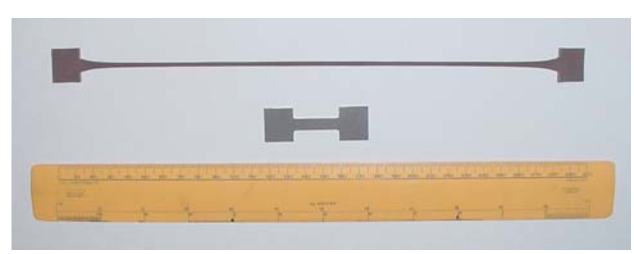

Fig. 2 Lower coupon is unformed. Upper coupon is SPF'd to 800% elongation

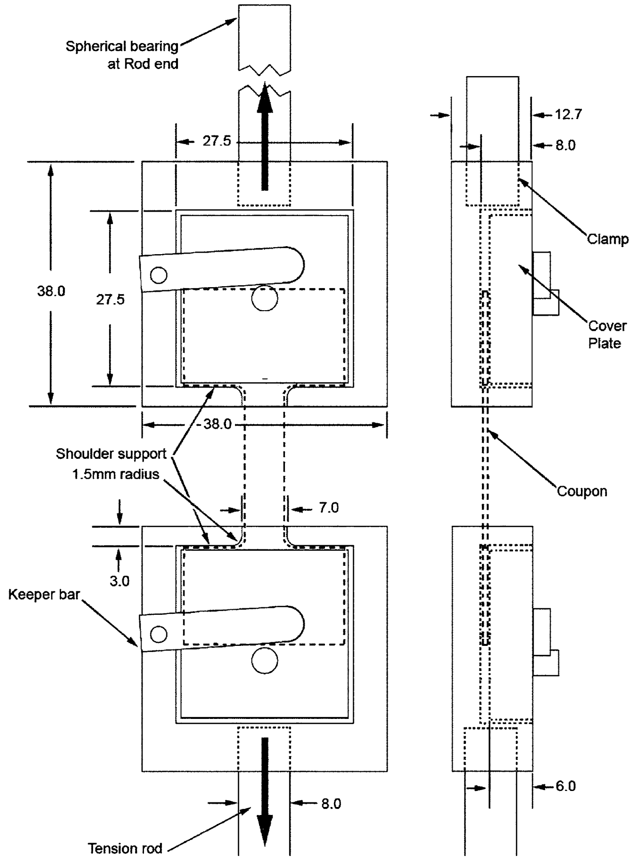

Fig. 3 Typical clamping arrangement

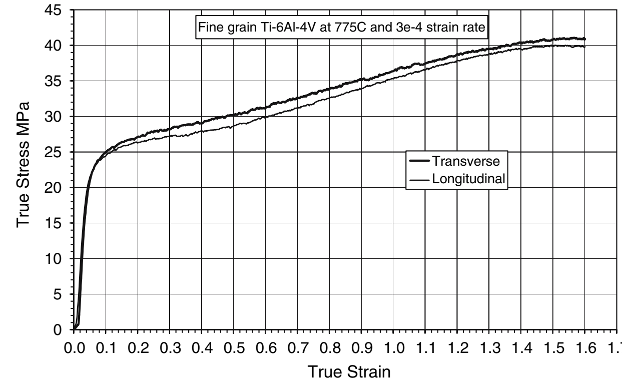

Fig. 4 Basic SPF properties of a material

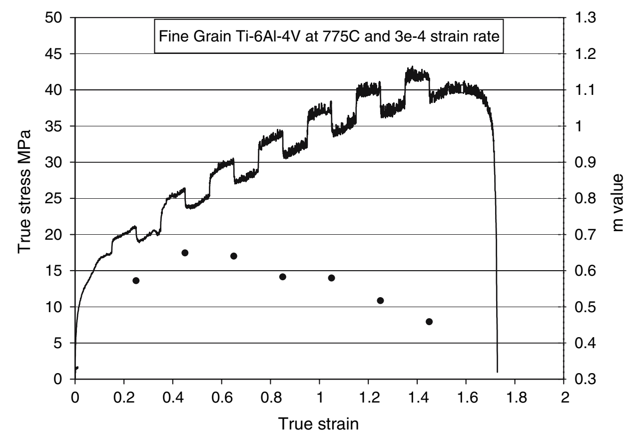

Fig. 5 Determination of '*m*' value

the amount of time needed to fully stabilize the temperature can be quite long, and there is a danger of grain growth, oxidation or other detrimental change in some materials that affects its superplastic properties. It is therefore acceptable to start the test when all the thermocouples are within the specified tolerance range, rather than the setpoint temperature. The ASTM test method specifies a tolerance of ±3 °C for test temperatures up to 700 °C, and ±6 °C above 700 °C. With practice, test houses for Boeing have found they can start the test at 775 °C within 20-25 min of loading the specimen.

The crosshead position is zeroed and the test is then started, with the crosshead speed determined by the following formula

$$V = \dot{\varepsilon}[L_0(1 + e)] \quad \text{(Eq 3)}$$

where $\dot{\varepsilon}$ is the desired strain rate.

As the value of e increases, so does the crosshead velocity, to maintain a constant strain rate. It is permissible to have incremental step changes in crosshead speed, as long as the variation from nominal strain rate is less than 1%. The test continues until failure or a predetermined strain is reached. During testing, the force and crosshead extension are measured at least twice per second.

6. Analysis-Basic SPF Properties

The basic SPF properties of the material are calculated from the load and extension data generated by the test, and presented as a graph of true stress (Eq 1) on the '*y*' axis versus true strain (Eq 2) on the '*x*' axis. A number of tests at different strain rates, temperatures etc. can be presented on the same graph. A typical graph is shown on Fig. 4. It may be convenient in some cases (for example the curve in Fig. 4) to represent the curve by an equation of the type $\sigma = \sigma_0 + k\varepsilon$, although this is not covered in the ASTM standard.

7. Analysis-'*m*' Value

The strain rate sensitivity exponent *m* is a derived property defined by the equation

$$\sigma = k_1 + k_2\dot{\varepsilon}^m \quad \text{(Eq 4)}$$

It is determined by a step test, where the strain rate is periodically stepped up to 20% above nominal, then back down again starting at a strain of 0.15 and stepping every 0.1, as shown in Fig. 5. A linear regression analysis is taken for stress values and extrapolated up to each step point.

$$m = \log(\sigma_2/\sigma_1)/\log(\dot{\varepsilon}_2/\dot{\varepsilon}_1) \quad \text{(Eq 5)}$$

The value of '*m*' usually varies depending on temperature, strain rate, and strain, therefore these conditions should be stated when quoting an '*m*' value for a material (Ref 2). For fine grain Ti-6Al-4V at 775 °C and pulled at 3 *e*-4/sec, it can be seen in Fig. 5 that '*m*' varies between 0.45 and 0.65 depending on strain.

8. Conclusion

The ASTM method E2448 has been developed to determine both the basic superplastic properties of a material and the derived value '*m*.' It has been designed to be easy to use and to give stable and repeatable results regardless of the test machine used. Therefore published data from different sources should be able to compare properties without compromise or adjustments. The standard can be used both for basic research into SPF materials and for industrial applications such as qualification of a heat lot of material for sale. The standard is periodically revised, and comments and suggestions to change or modify it are welcomed by the author.

Acknowledgment

The ASTM test method closely follows the practice of the PNNL (Ref 3-5) who had previously developed the coupon configuration and procedure.

References

1. A.K. Ghosh and C.H. Hamilton, Influences of Material Parameters and Microstructure on Superplastic Forming, *Met. Trans. A*, 1982, **13A**, p 733–742
2. F. Abu-Farha and M.K. Khraisheh, On the High Temperature Testing of Superplastic Materials, *ASM J. Eng. Mater. Perform.*, 2007, **16**(2), p 122–149
3. M.A. Khaleel, K.I. Johnson, C.A. Lavender, M.T. Smith, and C.H. Hamilton, Specimen Geometry Effect on the Accuracy of Constitutive Relations in a Superplastic 5083 Aluminum Alloy, *Scripta Mater.*, 1996, **34**(9), p 1417–1423
4. K.I. Johnson, M.A. Khaleel, C.A. Lavender, and M.T. Smith, Accuracy Issues in Modeling Superplastic Metal Forming, *Superplasticity and Superplastic Forming*, A.K. Ghosh and T.R. Bieler, Ed., The Minerals and Metals and Materials Society, 1995
5. K.I. Johnson, et al., The Effect of Specimen Geometry on the Accuracy of Constitutive Relations in a Superplastic 5083 Aluminum Alloy. *Proceedings of the 1994 International Conference on Superplasticity in Advanced Materials*, May 24-26, 1994 (Moscow, Russia)