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Temperature effect on the strength of a spray deposited Si-Al alloy for space application

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Introduction

New materials were recently developed to satisfy the rising requirements of thermal dissipation, densification and weight decrease of on-board electronic devices intended to satellites. These new materials are promising candidate materials to manufacture boxes for computing chips.

This paper deals with a study about the Si-Al CE9F designed by Sandvik Osprey™, an alloy containing 60 wt% of silicon. This material is characterized by a low coefficient of thermal expansion ($9e-6 \text{ K}^{-1}$), a high thermal conductivity ($130 \text{ W.m}^{-1}.\text{K}^{-1}$) and a low density (2.46) [1] that makes this material attractive for space applications, specially optical housing, chips packaging, sensors carriers, lens holders for laser systems and also to solve SWaP (size, weight and power) issues.

This study is focused on the mechanical properties of Si-Al alloy in the -50°C to 130°C temperature representative of the space applications.

Experimental Method

Spray deposited Si-Al alloy is prepared by atomization process developed by Osprey Metals Ltd[2]. A preliminary study on fracture surfaces shows that the Si-Al alloy has brittle fracture behaviour. Indeed, SEM pictures of fracture surfaces highlighted cleavage plans, as can be seen on Figure 1 and represented by striations. These plans are a specific feature of brittle fracture. That's why the mechanical samples were designed

according to the standard EN-843 – “Mechanical properties of monolithic ceramics”. The protocol of mechanical tests also follows the same standard ensuring the repeatability of testing campaigns.

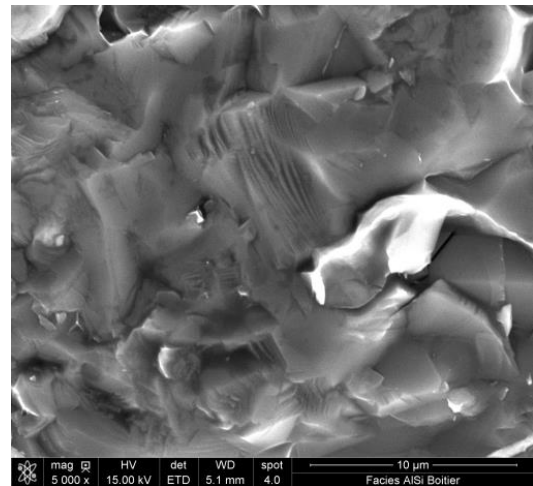


Figure 1: SEM picture showing the cleavage plans, special feature of brittle fracture

$45 \times 4 \times 3 \text{ mm}^3$ samples were machined and without a special surface treatment. For each testing temperature (-50°C , 20°C and 130°C), the samples were subjected to a 4 points bending test until fracture. The tests were performed at a crosshead displacement rate of 0.5 mm/min .

Then, the strength values were noted and analysed through the Weibull's theory, mainly used to understand the brittle fracture behaviour. This theory supposes the presence of critical flaws leading to the brittle fracture [3][4]. However, there is no relationship between this theory and the material's microstructure. The theory doesn't consider the size or the orientation of flaws but only the concept of “weakest link of a chain” where one flaw is enough to cause rupture. This

statistical method is used to relate the probability of failure P to failure stress σ through the empirical formula given below.

$$P = 1 - \exp \left[-V \left(\frac{\sigma}{\sigma_0} \right)^m \right]$$

Where m is the Weibull modulus determined experimentally, V is the effective volume of sample calculated according to the Weibull's theory, σ_0 is the scale parameter. These parameters are identified from the values of stress fractures by the maximum likelihood method [5]. Finally, for each testing temperature, a couple of Weibull parameters is obtained.

Results

For each testing temperature, the dispersion of stress fracture values was low. The table 1 sums up the mechanical results of 4 points bending tests. The average stresses are the same irrespective of the temperatures. Nevertheless, there is a significant difference about the minimum stresses: the dispersion is higher at 20°C than at the other temperatures.

Temperature	-50°C	20°C	130°C
Average failure Stress (MPa)	283	282	282
Max Stress (MPa)	303	295	299
Min Stress (MPa)	255	234	265
Number of Samples	20	29	30

Table 1: Sum up about 4 points bending strength

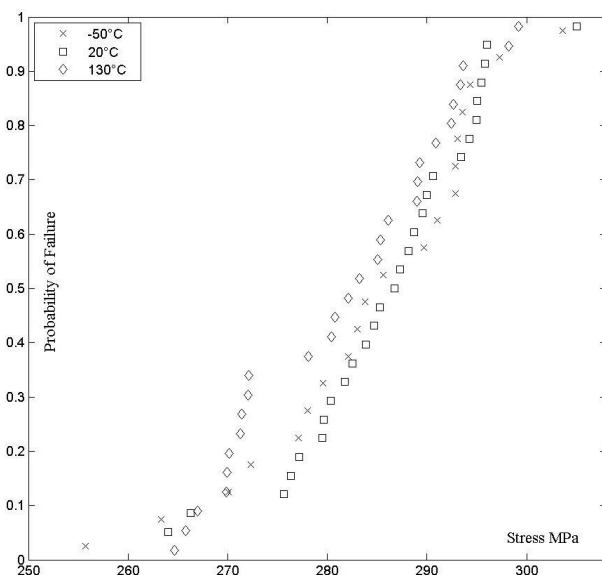


Figure 2: Weibull Distributions of 4 points bending tests for the 3 testing temperatures

The three distributions of failure stresses follow a Weibull's curve, which means that the fracture is led by one kind of flaw, either in surface or in volume. The table 2 presents both Weibull parameters describing the previous curves.

Temperature	-50°C	20°C	130°C
Weibull modulus m	27.9	29.8	29.4
Scale parameter σ_0 (MPa)	304	303	300

Table 2: Weibull parameters for the 3 testing temperatures

The Weibull parameters are almost the same for all testing temperatures. These results show the independence of material's strength to working temperature. Despite this high Weibull modulus value, the significant gap between the minimum and the average stress requires to consider a probabilistic model. Indeed, in the Weibull model, the probability zero does not exist: even for very low loads there is still a risk of fracture.

Conclusion

This study shows the brittle behaviour of Si-Al alloy and so the relevance of using a Weibull model. It also shows the mechanical properties' independence of spray deposited Si-Al alloy along with working temperatures related to space application. Later study will be realized to determine the thermal aging effect on the mechanical properties of Si-Al alloy.

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