FRACTURE SURFACES OF Al_2O_3/Al-ALLOY COMPOSITES

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SUMMARY : After tension, creep, fatigue and fracture toughness tests for Al_2O_3 short fibers reinforced two Al-alloy composites, Al_2O_3/Al-7Si-0.6Mg and Al_2O_3/Al-5Si-3Cu-1Mg, the fracture surfaces were studied. Macroscopically, fracture surfaces for the two composites were very different and dominated by the plasticity of matrix at the test conditions. Microscopically, dimples existed in two matrixes fractured, which showed ductile rupture features. Plastic deformation zone near cracks in Al_2O_3/Al-7Si-0.6Mg composite was much larger than that in Al_2O_3/Al-5Si-3Cu-1Mg composite. Fatigue striation loops in fracture surfaces indicated that fatigue crack propagation in the composites was made by linking striation loops around each broken fiber. Few broken fibers can be observed in the fracture surfaces for the tensile specimens ruptured at temperatures above 300 ^{o}C, in which almost all broken fibers were deeply embedded into the matrix in shape of sleeve.

KEYWORDS: Al_2O_3/Al-alloy composite, fractography, fatigue, creep, tension, fracture toughness, plastic deformation, material damage

INTRODUCTION

In general, the properties of short fibers reinforced composite is between those of continuous fiber reinforced composite and particulate reinforced composite. Nevertheless, as for metal matrix composites (MMCs), from the point of fabrication and secondary processing, short fibers reinforced composites are superior to continuous fiber reinforced composites, and can be compared with particulate reinforced composites. Hence, short fibers reinforced MMCs, as a new kind of material, should be studied from all aspects concerning engineering before being applied widely. Fracture feature is an important one of the aspects. The study on this subject has been paid much attention to unidirectional, laminate composites or particulate reinforced MMCs[(1- 2)]. As for short fiber reinforced MMCs, especially when the fibers are dispersed randomly, whose fracture mechanism is more complex, little attention has be paid to their fracture features. The study of fracture surfaces is benefit to studying fracture mechanism of the materials. Evidently, ceramic reinforcements in MMCs reduce plasticity of the matrix metal. Do they influence fracture mechanism? How is the fracture surface morphology for random short fibre MMCs? These are the research subjects in this paper.

EXPERIMENT PRODURES

Two Al-alloy composites reinforced with δ–Al_2O_3 short fibers of 20% in volume, Al_2O_3/Al-7Si-0.6Mg and Al_2O_3/Al-5Si-3Cu-1Mg in which the fibers were dispersed randomly, were fabricated by squeeze casting, and then applied to following heat treatments:
For Al_2O_3/Al-7Si-0.6Mg: solution at 510^{o}C for 6hrs → water quenching (70^{o}C) → temper at 160^{o}C for 6hrs.
For Al_2O_3/Al-5Si-3Cu-1Mg: solution at 540^{o}C for 6hrs → water quenching (25^{o}C) → temper at 160^{o}C for 6hrs.
After that, tensile tests at both room temperature and elevated temperatures from 200 to 350^{o}C, creep tests at 300^{o}C, fatigue tests in tension-tension at load ratio of 0.1 and fracture toughness tests at room temperature were performed on two composites, using an Instron 115 material test machine. The specimens of rectangular cross-section were used for tension, creep and fatigue tests, whose design is shown in Fig.1. Single edge notched specimens were used to measure fracture toughness, the dimensions were decided according to ASTM E399-83 standard. Surfaces of some specimens were polished before testing, and examined with scanning electrical microscope (SEM) or optical microscope after tests. Fracture surfaces of specimens were examined firstly with a binocular macrofractography equipment at magnifications from 2 to 10x to see the whole morphology, and then with SEM at magnifications from 1000 to 10000x to observe details in some feature zones, for example, fatigue cracks propagation zone, plastic deformation zone near the crack in fracture toughness specimens and so on.

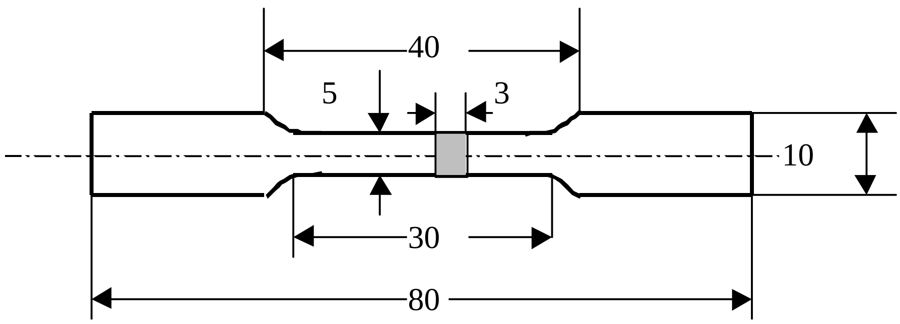


Fig.1. Dimensions of the specimens used for tension, fatigue and creep tests

RESULTS AND DISCUSSIONS

Macroscopically, fracture surfaces of Al_2O_3/Al-7Si-0.6Mg composite subjected to creep tests, tension tests at both room temperature and elevated temperatures were inclined at an angle of about 45^o to the loading direction, as shown in the right of Fig.2. It follows that the specimens were fractured by shear and it was a ductile fracture mode like that of the matrix alloy alone. This indicated that the fibers of 20% in volume did not significantly affect on the macroscopic morphology of fracture surface for the composite, even though the ceramic fibers decreased substantially matrix alloy plasticity; in other words, the matrix alloy dominated macroscopic morphology of fracture surfaces for the composite. However, for Al_2O_3/ Al-5Si-3Cu-1Mg composite, the result was different. Their fracture surfaces after tension tests varied with test temperatures, the fracture surfaces ruptured at room temperature were flat as shown in the left of Fig.2; most of the fracture surfaces ruptured at the temperature below 250 ^{o}C were still flat. Only when test temperature was elevated to above 300^{o}C, their fracture surfaces were close to those described previously for Al_2O_3/Al-7Si-0.6Mg composite. The difference in fracture surface between two composites resulted from the difference in plasticity. Rupture strain at room temperature for Al_2O_3/Al-7Si-0.6Mg composite was 1%, while that for Al_2O_3/Al-5Si-3Cu-1Mg composite was only 0.6%. This difference was decreased with temperature because age-hardening effect was decreased with temperature due to precipitating some alloy additions at elevated temperature as shown in Fig.3. It was this reason that the fracture surfaces for Al_2O_3/Al-5Si-3Cu-1Mg composite varied with the test temperatures. It seems that rupture strain of about 1% is a critical strain for the transfer from ductile fracture to brittle fracture. When rupture strain of composite is small than 1%, the composite shows brittle fracture, or else, it shows ductile fracture.

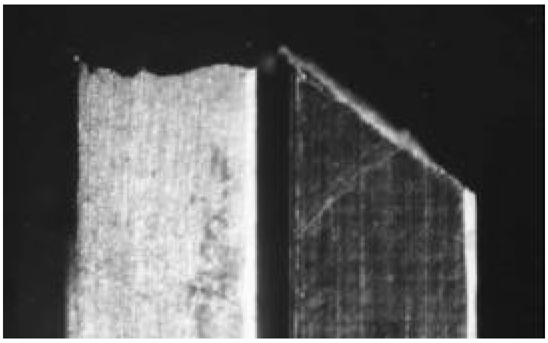


Fig.2. Profile of the fracture surfaces of Al_2O_3/Al-7Si-0.6Mg (right) and Al_2O_3/ Al-5Si-3Cu-1Mg (left) composites ruptured in tension or creep tests (10x)

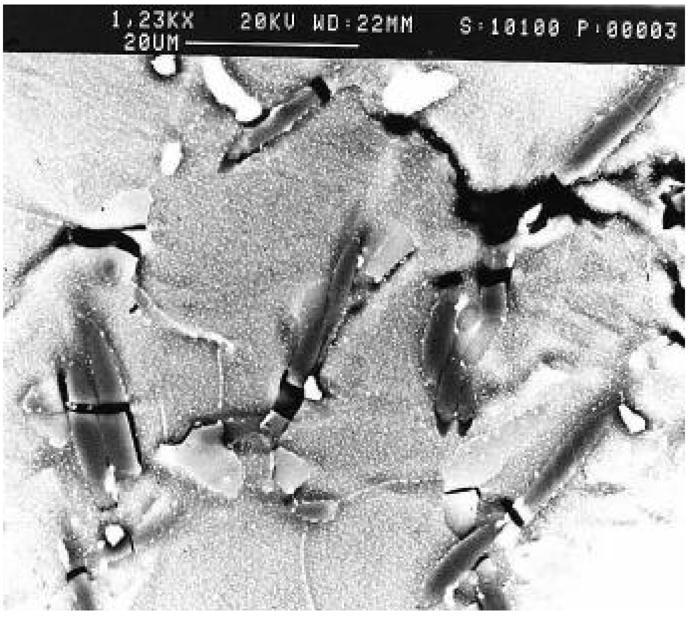


Fig.3. Precipitates (white small dots or line) in Al_2O_3/ Al-5Si-3Cu-1Mg subjected to tension or creep tests at 300 ^{o}C

The fatigue fracture surfaces of the two composites were also different. For Al_2O_3/Al-7Si-0.6Mg composites, crack propagation region and fast fracture region can be distinguished easily; and the fast fracture region was a shear lip. The shear fracture percentage in fatigue fracture surfaces of the composite depended on load severity; a great load resulted in a large shear lip, while a small load resulted in a small shear lip as shown in Fig.4. As for Al_2O_3/Al-5Si-3Cu-1Mg composite, crack initiation region was more visible than that for Al_2O_3/Al-7Si-0.6Mg composite, but it was too difficult to distinguish crack propagation region and fast fracture region, and no obvious shear lip can be observed; the fatigue fracture surfaces were flat. Also, the fracture surfaces after fracture toughness tests for the two composites showed the differences described previously: one with small shear lip, the other without shear lip. Evidently, this difference in macroscopic fracture surface between two composites resulted also from the difference in plasticity as discussed previously for tensile fracture surfaces.

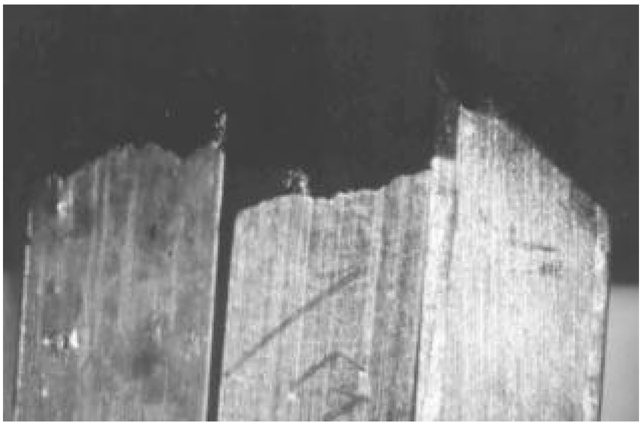
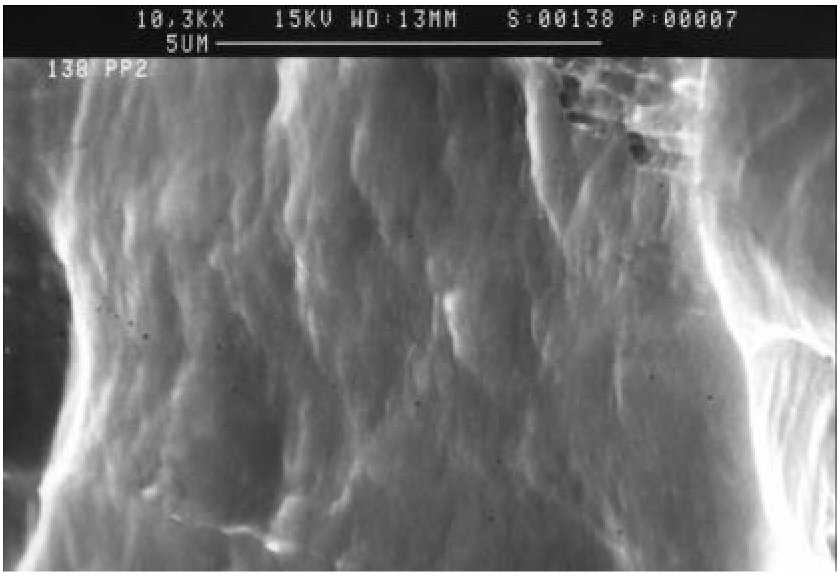
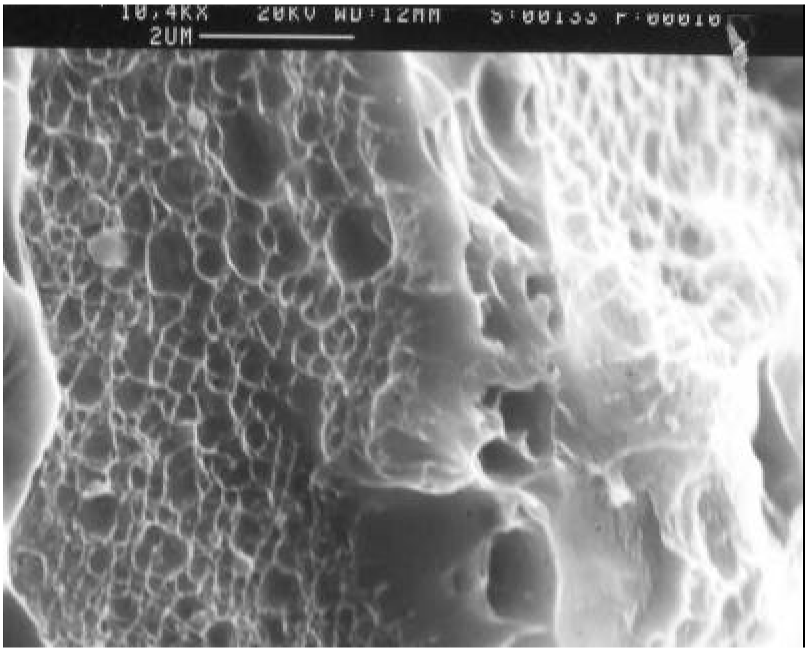


Fig.4. Profiles of fatigue fracture surfaces of Al_2O_3/Al-7Si-0.6Mg composite at different cyclic loading (maximum load from right to left: 165Mpa→150Mpa→135Mpa) (10x)

Microscopically, it was observed that dimples existed in the two matrixes fractured, no matter which test the composites were subjected to. However, the dimples in fracture surfaces of the two composites were also very different. The dimples in the fracture surface of Al_2O_3/Al-7Si-0.6Mg composite were long strip cavities while those in the fracture surface of Al_2O_3/Al-5Si-3Cu-1Mg composite tested at ambient temperature were small spherical microvoids as presented in Fig.5. Existence of dimple indicates that microscopically, the two composite matrixes were fractured by microvoid nucleation, growth and coalescence as described in references (3), (4) and (5); even though macroscopically, Al_2O_3/Al-5Si-3Cu-1Mg composite showed brittle rupture features. Nevertheless, microvoids in Al_2O_3/Al-7Si-0.6Mg composite were much elongated due to its good ductile so that the dimples were in the shape of long strip. That is the reason why dimples in two composites were so different.



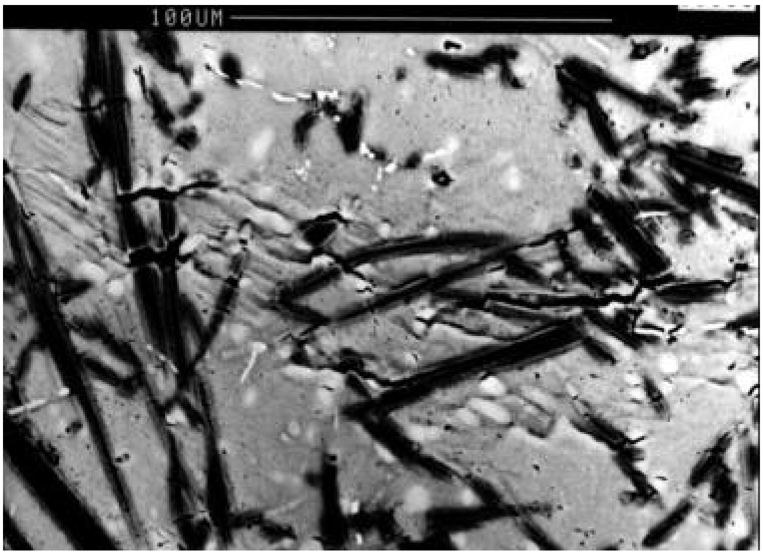
a. Al_2O_3/Al-7Si-0.6Mg composite



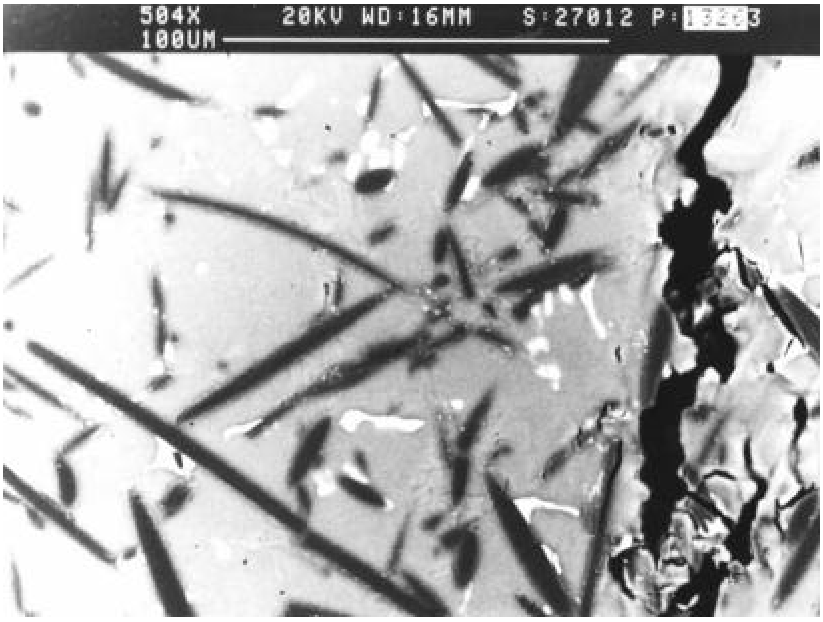
b. Al_2O_3/Al-5Si-3Cu-1Mg composite

Fig.5.Dimples in fracture surfaces of two composites ruptured at room temperature

Compared surfaces of specimens performed fracture toughness tests, which were polished before tests, it can be observed that plastic zone near the cracks in the Al_2O_3/Al-7Si-0.6Mg composite was much larger than that in Al_2O_3/Al-5Si-3Cu-1Mg composite (see Fig.6.) But the fracture toughness value of Al_2O_3/Al-5Si-3Cu-1Mg composite was greater than that of Al_2O_3/Al-7Si-0.6Mg composite(6). It suggests that fracture toughness for Al_2O_3/Al-7Si-0.6Mg composite should be principally contributed due to work dissipated by plastic deformation of the crack tip; while that for Al_2O_3/Al-5Si-3Cu-1Mg composite should principally attributed to formation of the fracture surfaces. This result indicates that increasing the fracture toughness of these materials can only result from microstructure changes that enhance either the ductility of the matrix or surface formation energy.



a. Al_2O_3/Al-7Si-0.6Mg composite



b. Al_2O_3/Al-5Si-3Cu-1Mg composite

Fig.6. Plastic deformation near cracks in two composites ruptured in fracture toughness tests

Fatigue crack initiation sites for the composite specimens tested were near a surface, at weak fiber/matrix interfaces, or defects like inclusion and cavity in the composite[7]. In fatigue crack propagation region of the composites fracture surfaces, some ambiguous ductile fatigue striations can be observed by scanning electrical microscope. Some of them were loop fatigue striations around fibers as given in Fig.7. It suggested that the crack should be propagated taking the fiber as a center, i.e. firstly the fiber should be damaged, and a crack should be initiated then the crack should be propagated towards to radial direction around the broken fiber. With the crack propagation, fatigue striation loops around neighboring several broken fibers were linked into a big one. Some of them were close, if there were no fibers near them, that means the fibers were clustered in the matrix, otherwise, fatigue striation loops can not be close ones. That is why most of the fatigue striations were arcs with various curvatures. The microscopic fractography for fast fracture region in fatigue fracture surface was like that in tensile fracture surface.

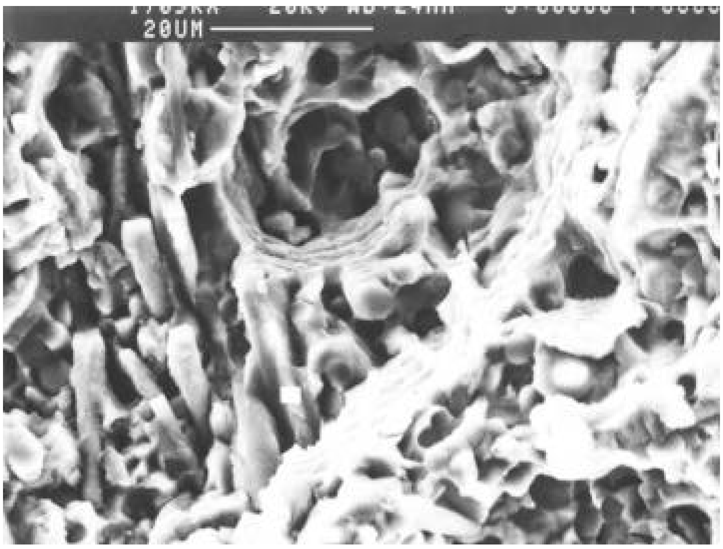


Fig.7. Fatigue strips in fracture surfaces of the composites

The fractography of the composites tested in tension at elevated temperatures depended upon the test temperatures. Some broken fibers can be observed in the fracture surface when the specimen was fractured at the temperatures below 250 ^oC. Few broken fibers were discovered in the fracture surface for the specimens ruptured at the temperatures above 300 ^oC, in which almost all broken fibers were deeply embedded into the matrix in shape of sleeve as shown in Fig.8. The higher the test temperatures, the longer the sleeves. It suggests that matrix should be elongated freely after the fibers in it were broken, which was approved by stress-strain curve shown in Fig.9. In fact, stage III in fig.9 was creep of the matrix near the ends of the broken fibers. Therefore, creep fractography of the composites at 300 ^oC was similar to tensile fractography of the composites tested at the same temperature.

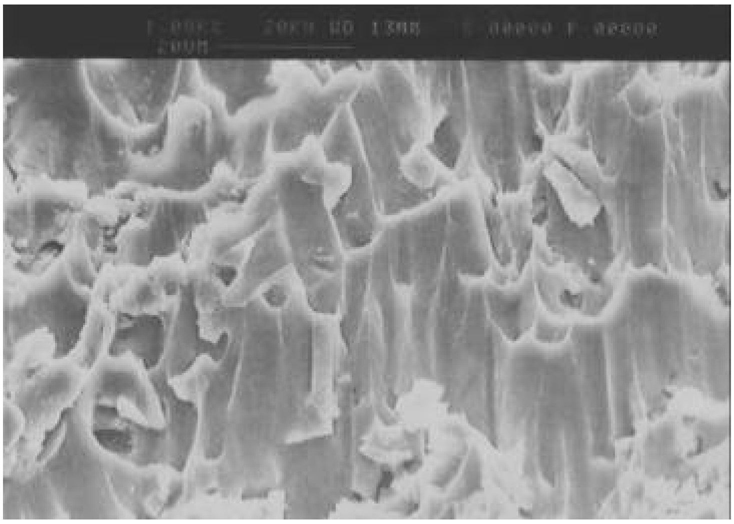


Fig.8. Fracture surface for the composites rupture at 300 ^oC

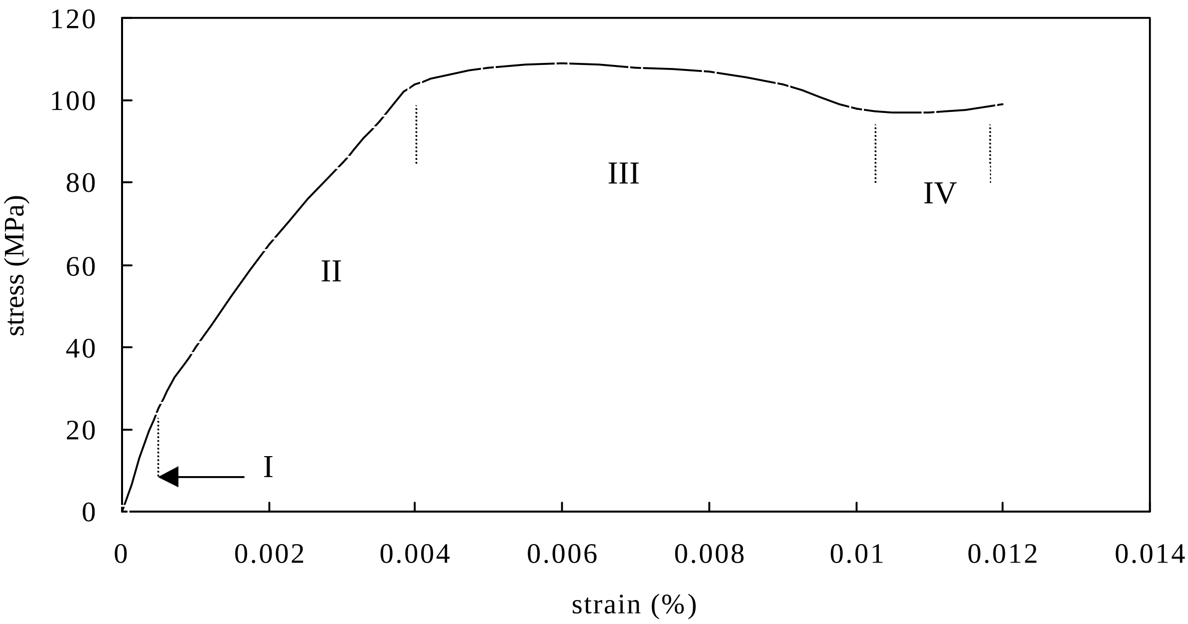


Fig.9. Stress-strain curve for the composite tested at 300 ^oC

SUMMARY

Macroscopically, fracture surfaces for the two composites were very different and dominated by the plasticity of matrix at the test conditions. Microscopically, dimples existed in two matrixes fractured after test, which showed ductile rupture features. Plastic deformation zone near cracks in Al_2O_3/Al-7Si-0.6Mg composite was much larger than that in Al_2O_3/Al-5Si-3Cu-1Mg composite. The striation loops in fatigue fracture surfaces indicated that fatigue crack propagation in the composites was made by linking striation loops around each broken fiber. Few broken fibers can be observed in the fracture surfaces for the tensile specimens ruptured at the temperatures above 300 ^{o}C, in which almost all broken fibers were deeply embedded into the matrix in shape of sleeve.

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