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Influence of Strain Rate on Metal Matrix Composites

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Abstract

Many metallic materials show in their mechanical behaviour a significant dependence on the deformation speed. The behaviour of a material subjected to variable loads over time shows two important differences in relation to its behaviour under static conditions: one is the participation of inertial forces in equilibrium, and the other is the possible influence of the deformation speed on the material properties. In general, an increase in the deformation speed results in an increase of the yield point and maximum strength. The complexity of the behaviour of these materials, together with their recent origin, has meant that most studies have focused on their behaviour at low strain rates. Thus, for example, the effect of breakage of SiC particles, which exhibit a brittle behaviour, have been studied. These particles break progressively during plastic deformation, and the probability of breakage is much higher as the size of the reinforcement increases. This fact implies negative effects such as the reduction of the particle-reinforced composites (PRC's) tensile strength and the precipitation of final breakage.

Keywords: metal matrix composite, metallic materials, strain rate, mechanics of the fracture, particle-reinforced composites.

1 Introduction

From 1961 onwards, materials in use (mainly aluminium) were considered to be more sensitive to deformation speed when this speed was higher than 1000 s-1. From the point of view of solid mechanics, this increase in sensitivity to the strain rate can be attributed to inertial effects; from a physical point of view, sensitivity to the strain rate is attributable to the abrupt transition from thermal to viscous behaviour. Several authors [1-3] have studied the evolution of the damage during a tensile test using two indirect methods which are the location of changes in density and Young's modulus. The damage parameter deduced from the density changes for a given deformation is one or two orders of magnitude smaller than the parameter based on Young's modulus changes.

The same authors have analyzed the influence of damage on the tensile behavior of pure aluminum reinforced with more than 40% vol. alumina particles. The internal damage, quantified in the form of fractured particles and voids in the matrix, occurs from the beginning of the plastic deformations and results in changes in stiffness and stress peaks during the increase of plastic deformation. The breakage deformation varies between 2 and 4 %, and is a function of the estimated damage accumulation. The authors have proposed an expression to predict the elongation at break of damaged material that breaks due to plastic instability, an expression whose predictions are in good agreement with experimental observations [4].

In crystalline materials, the micro-mechanisms of damage are basically two: the cleavage or separation of crystalline planes and the nucleation, growth and coalescence of cavities until the material tears [5]. When deforming a solid by application of external actions and reaching breakage, it is generally possible to detect in the fractured region areas that are plastically deformed, areas with cleavage surfaces and areas in which the typical structure of coalescence of cavities can be distinguished. Breaks where cleavage is predominant are observed in crystalline materials at low temperatures or for high deformation rates. In most crystalline materials, from a certain temperature, the processes of nucleation, growth and coalescence of cavities predominate [6-8].

From a macroscopic point of view, ductile breakage is characterized by the previous development of important plastic deformations. The energy consumed in the deformation process is much higher in the ductile case than in the brittle one, where the breakage occurs with hardly any plastic deformation. The appearance of the fracture surfaces corresponding to a ductile fracture is a consequence of the mechanical processes resulting from the interaction between applied stresses, field of deformation and microstructure of the material. In summary, it can be said that ductile fracture occurs as a result of three processes:

- Nucleation of micro-vacuum during plastic deformation.
- Growth of the nucleated microvacuum.
- Coalescence of these to produce new free surfaces (cracks) and the final breakage of the component.

All these processes can take place simultaneously in the material: while there are microvacuum that grow and end up coalescing, new microvacuum are being nucleated and developing the process of breakage. If the fraction of microvacuum is low, it can be assumed that each microvacuum grows independently; above a certain volumetric fraction, the microvacuum interacts with each other (coalesces), forming fracture surfaces, through a process of intense localization of the deformation in the spaces between them [9-11].

In materials where inclusions and second phase particles are closely bound to the matrix, void nucleation is usually the critical step leading to immediate fracture. On the other hand, when the nucleation of voids occurs with certain difficulty, the dominant phenomena of the fracture process are the growth and coalescence of voids, which will grow to a critical size, producing a phenomenon of plastic instability (due to the location of the deformation in the space between them) that will finally lead to the breakage of the material [12]. A microvacuum is formed around non-metallic inclusions or second phases, either when the applied stress is sufficient to break the interfacial bonds between the particles (inclusions) and the matrix, or by a process of particle breakage due to the difference

2 METHODOLOGY

The steps to be followed will be the following:

1) Choice of appropriate impact. Firstly, a projectile impact will be sought that provides adequate tension in the test specimen. For this purpose, the maximum voltage of the incident wave shall be taken as the impact measurement parameter. To adjust the speed with which the projectile impacts, a pressure regulating valve will be used, which will control the air pressure reaching the projectile. After finding the appropriate pressure for the test, continue with the next point.

2) Modified Hopkinson bar test with the pressure chosen in point 1). The test piece shall then be placed on the modified Hopkinson bar model and tested at the pressure taken from the previous paragraph. At this point, the stress-strain curves of the material to be studied shall be obtained, at a deformation rate that will be imposed by the impact of the projectile. With these curves and the incident and transmitting bar waves, the results shall be contrasted with the damped tests.

3) Damped Hopkinson bar test. Finally, the damped Hopkinson bar tests shall be carried out, maintaining the projection pressure of the previous point. At this point, the thickness of the shock absorber shall be varied until a limit is found at which the test is stopped and data from the interrupted tests can be obtained. In order to carry out all the above explained, the equipment shown in the following image shall be used.

Figure 1. Equipment Hopkinson bar of damped traction of the University Carlos III of Madrid

This equipment has two different parts, on the one hand the testing tool, which would be the Hopkinson bar as a whole (bars, specimen, barrel, valves, casing, rings, etc.) and so on.

3 Results

The image shows the stress-strain curve of a specimen

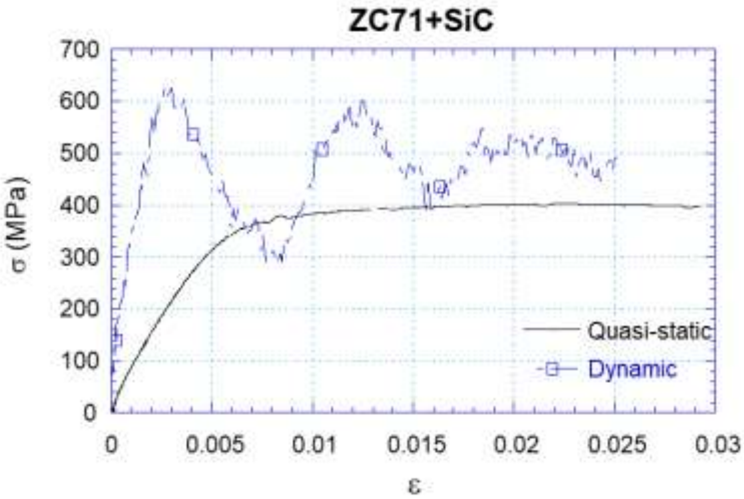

Figure 2. Stress deformation curve at high deformation speeds

Stress-strain curves at high strain rates are generally obtained by testing with the Hopkinson bar. The following results are obtained for SiC reinforced aluminium: the apparent modulus of elasticity does not vary practically for strain rates between 10-3 and 150 s-1, but increases from this value; the elastic limit does not vary practically for strain rates between 10-3 and 150 s-1, but increases from this value; the strain at break increases with the strain rate (which contrasts with the behaviour of other materials in which this strain decreases with increasing strain rate). The spatial distribution of the reinforcement particles within the matrix has a decisive influence on many of their mechanical properties (yield strength, ductility). Generally, the particles are not uniformly distributed in the matrix, since the plastic flow associated with the material extrusion process gives rise to the arrangement of the particles (Figure 3), or the appearance of clusters (Figure 4), depending mainly on the solidification speed.

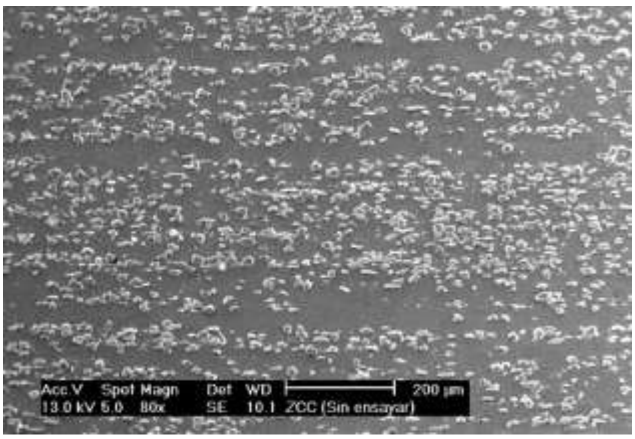

Figure 4. Banded particle sorting

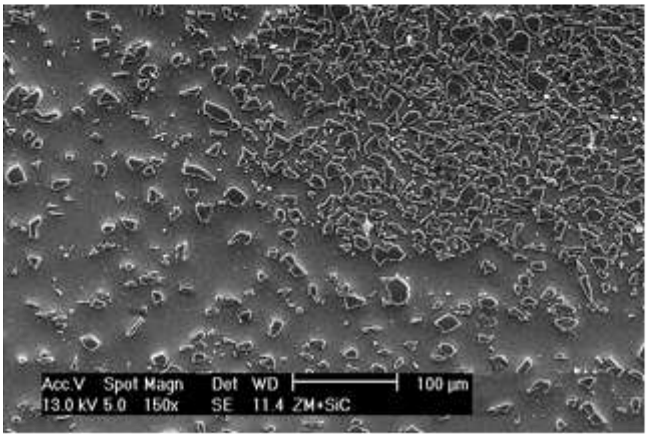

Figure 5. Cluster

The concept of particle clustering is used to describe two types of non-uniformity in particle distribution. In the first type, the distance between particles follows a Poisson distribution and is considered invariant to the position in space; this type of inhomogeneity ("local") is caused by nature. In the second type, the average value of the distance between particles in some regions is greater than the average in the region's surroundings; this type of inhomogeneity is due to the manufacturing process [13].

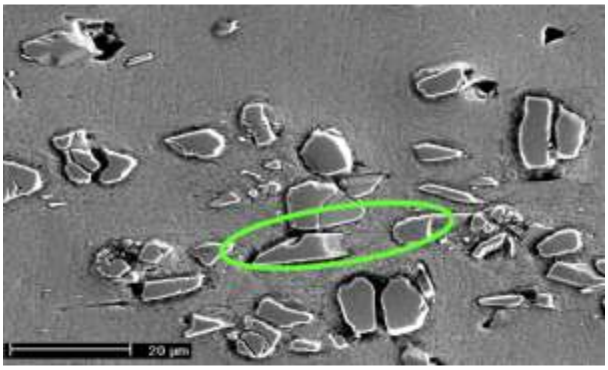

Figure 5. Broken particles

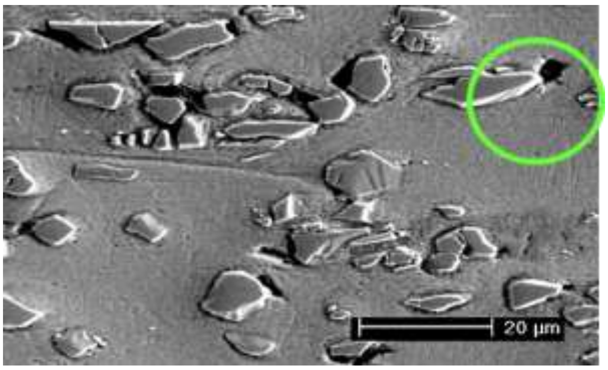

Figure 6. Decohesioned particles

Different studies [12-15] have shown that the damage mechanisms during deformation are mainly particle fracture and particle/matrix decohesion. In general, reinforcement breakage is the main damage process in commercial matrices and at room temperature while particle/matrix decohesion is mostly observed in low strength matrices or at high temperatures The breakage of reinforcement particles in commercial materials at room temperature occurs when the load is transferred from the matrix to the particles, which fracture in planes perpendicular to the direction of stress.

4. Conclusions

The breakage of the particles follows the following rules of behaviour:
- Long particles are more susceptible to breakage than small ones.
- Particles whose larger dimension is in the direction of the load are also more susceptible to breakage than those whose larger dimension is in the perpendicular direction to the load.
- Particle clusters are also regions where particle breakage occurs for minor deformations; this fact can be attributed to the high triaxiality generated in these regions.

In particle-reinforced composites (PRC's), microvacuum nucleation has been observed at the ends of long particles oriented parallel to the axis of action of the charge; however, complete particle decohessions are not frequently observed. The process of progressive damage follows the following stages:
-The stress on the intact particles increases during deformation due to progressive deformation hardening of the matrix.If a particle breaks, it relaxes the stress it was absorbing, which is then absorbed by the surrounding matrix.
-As the matrix exceeds its strain-hardening capacity, it cannot accept the stress relaxed by the particle that has broken.The tension relaxed by the particle's fracture is then transferred to the intact particles in the environment.
-The stress overload of the still intact particles causes them to break and the number of broken particles in a chain process increases accordingly. Initially, a homogeneous distribution of the broken particles is produced, although it tends to be located immediately in a given section of the specimen.

An important effect of the progressive and increasing breakage of particles during the plastic deformation process of the material is the decrease of the material's strain hardening speed compared to that of the base material. Thus, the point of plastic instability is reached earlier in the reinforced material. The final breakage of the specimen is produced by a ductile mechanism with nucleation, and growth of microvacuum in the matrix that coalesces with voids associated with particle breaks and particle/matrix decohessions.

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