Dynamic torsional behaviour of Al-based metal matrix composites with SiCp

Alaa Eldin Hassan Hamdy
Mechanical Engineering Department, Faculty of Engineering, Alexandria University, Alexandria Egypt

The behaviour of Al-Li8090 and Al-Li8090MMC at high strain rate and constant temperature is studied. Torsion Hopkinson bars testing device is adopted to obtain the shear stress-strain relationships at high strain rates and different temperatures for both materials. A constitutive equation is obtained for each material by fitting of experimental results.

تم دراسة خواص السبيكتين Al-Li8090 &Al-Li8090 MMC تحت أثير إجهاد قص بمعدل انفعال عـــالي (٢٥٠٠ث$^{-1}$) ودرجة حرارة عالية (حتى ٤٥٠م°) وقد استخدمت أعمدة هوبكنسون الالتوائية للحصول على إجهاد القص ســريع الانفعــال. وقد تم استنتاج علاقة رياضية من النتائج المعملية تربط بين تصرف السبيكة عند معدلات الانفعال المختلفة ودرجـــات الحـــرارة العالية.

Keywords: Dynamic torsional behaviour, Al-Li8090mmc, Hopkinson bars.

1. Introduction

As modern aerospace materials are being manufactured, formed, and used in more extreme environments, it is very important to be able to study the plastic deformation and workability of the materials. Metal Matrix Composites (MMC) based on Al are becoming extremely important to the aerospace industry.

The high strain rate modelling of materials have been extensively studied over recent years and several forms of constitutive equations for composite materials were presented [1-4]. However, to the author's best knowledge; no data or constitutive equation describing such behaviour for the metal matrix composites based on Aluminium (AL. Based MMCs) is available.

The objectives of this work is to develop and conduct fundamental mechanical test on the materials under high strain rate to identify the important global parameters which can lead to shear localisation and failure under these conditions. This type of loading is not uncommon in impact loading of structures such as armour penetration, explosive loading, fragmentation of bombs, erosion and impact of surfaces and high speed machining. Also development of constitutive equations which will include strain rate and temperature effects.

2. Experimental set-up

torsion Hopkinson bars (THPB) testing machine shown in Fig. 1. [5], adapted for temperatures up to 550°C, was used to carry out the experiments consists of two elastic cylindrical bars (AZ8GU-T6), 30mm diameter, supported by means of 9 bearings at a large square iron section. At the end of one of these bars a hydraulic system is used to rotate the bar, on the same bar a brace is settled to store the energy and then release it by cutting a steel screw which holds the brace, the torsion moment will propagate along the bar to reach the specimen and part of it will pass through be the specimen to the other bar. The other part will reflected , this moment measured by full bridge gages placed on each bar.
From this measurement we are able to define the following;

$$\tau(t) = \frac{T_2(t)}{2\pi\, r_m^2 e},$$

$$\dot{\gamma}(t) = \frac{r_m}{L}\left[\omega_1(t) - \omega_2(t)\right]$$

$$\omega_1(t) = \frac{T_i(t) + T_r(t)}{J\rho C}, \qquad \omega_2(t) = \frac{T_2(t)}{J\rho C}.$$

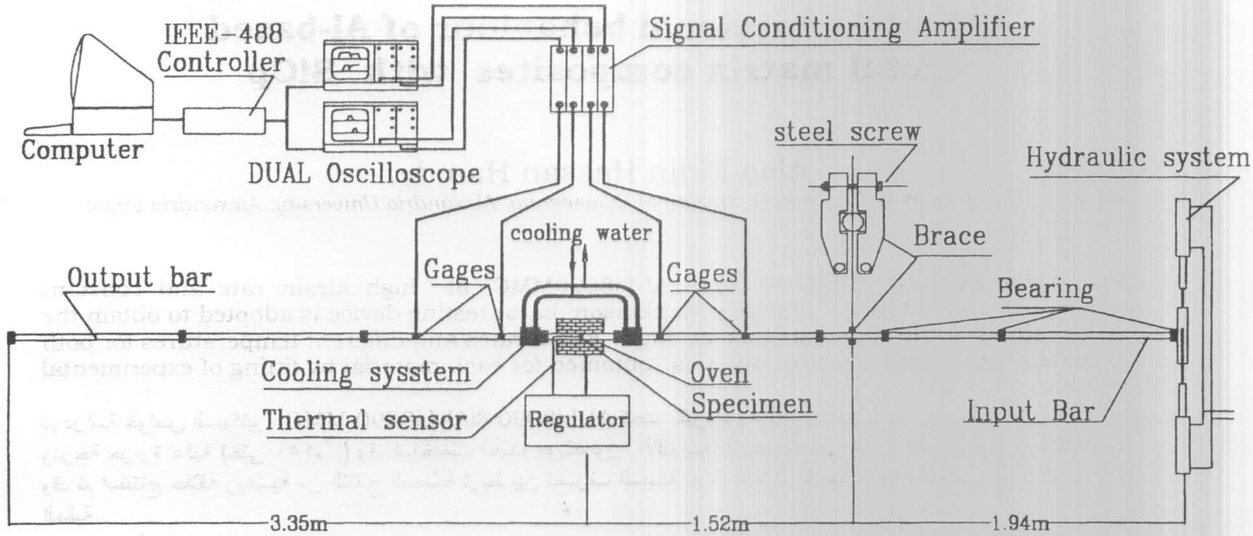

Fig. 1. Torsion Hopkinson testing machine.

Where:

- τ is the shear stress in the specimen
- γ is the shear strain in the specimen
- T_2 is the torque measured at the output bar
- T_I is the incident torque measured at the input bar
- T_r is the reflected torque measured at the input bar
- J is the area moment of bar
- ρ is the bar density
- C is the sound velocity in the bar
- L is the specimen gage length
- r_m is the specimen mean radius

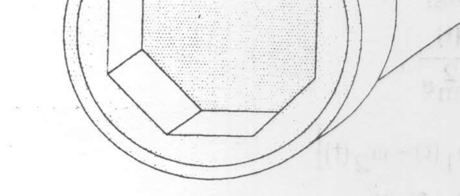

Fig. 2. Bar's end.

3. Modifications

1) Two full bridge gages located at each bar at 0,5&1m distance from the specimen to measure the dispersion of the stress wave in the bar (as it occurs when the bar is subjected to a temperature's gradient), then the exact value of the torque and rotation at the end of the bar (just before the specimen) can be calculated. These four load cells were calibrated by means of weights.
2) The high temperature tests have been carried inside electrical oven regulated by means of a regulator and thermal sensor.
3) To protect the strain gages, a cooling system with running water is used before and after the oven.
4) The specimen is fixed with the bar by means of prismatic hole in the bar's end with 6 mm depth as shown in Fig. 2, the bar's end have been reinforced with steel ring.
5) The measuring system is used to measure and amplify the four signals from the bridges by means of four Signal Conditioning amplifiers, then transfer them to two storage dual oscilloscope (150MHz) which are connected to the computer through IEEE-488 Controller to save all of them on a disc .

6) A computer program has been used to calculate the stress, strain , strain rate and time relationship at the specimen.

4. Specimen's material, geometry and dimensions

Two materials were tested:
1- Al - Li 8090 with no additions,
2- Al - Li 8090 + 20 wt% SiC (particles).

These materials made by powder metallurgy techniques, in the two materials there will be particles produced by age hardening and with the second MMCs also SiC particles. Thus there is a whole rang of hardening particles in these materials.

The two materials were supplied as 4 plates (two for each)12.5mm in thickness, it will be noted by "A" for one plate and "B" for the other. From each plate about 24 specimens were machined using the middle area to avoid the cracks at the edges of the plates. The specimens orientation must be perpendicular to the plate because of its dimension Fig. 3.

Three gage lengths were machined to three different strain rates tests. All specimens were quenched and annealed about 24 hours before the test. Fig. 4. shows the specimens geometry.

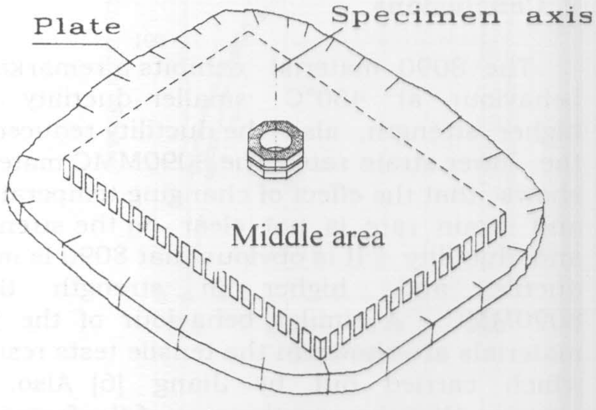

Fig.3.Specmen dimensions.

5. Constitutive equations

Modelling of materials at high strain rates and temperatures have been extensively studied over recent years, C. Y. Chiem and Z. G.Liu [1] proposed a modified Norton-Hoff version of constitutive equation for a waven glass fibre/epoxy composite in the form;

$$\tau = k\gamma^{\alpha}(\dot{\gamma})^{\beta}(1-\frac{T}{T_g})^{b}\ .$$

Where:

T is the absolute temperature in the specimen= room temperature + temperature rise during the deformation,

T_g is the glassy transition temperature ,

α , β, b and k are constants.

J. Harding [2] has reviewed and discussed the theoretical basis of various constitutive relationships and there applications limits. Lawson and Nicholas [3] used the form ;

$$\tau = f(\gamma) + a\ln(1 - b\dot{\gamma})\ ,$$

where:

$f(\gamma)$ is the shear stress -shear strain relationship at static test,

γ & $\dot{\gamma}$ are the shear strain and shear strain rate ,

a & b are constants , this equation could be written in the form;

$$G\dot{\gamma} = k(\exp(\frac{\tau - f(\gamma)}{a}) - 1)\ ,$$

where; G is the modules of rigidity and k is constant this relation could be applied at constant temperature .To characterise the TITAN T.40 at high shear strain rate. J. L. Lataillade et al. [4] fined that the equation;

$$\dot{\gamma} = c(\frac{\tau}{\tau_0} - 1)\ ,$$

fit the experimental results at constant temperature where τ_o is the yield shear stress at very low shear strain rate .

We propose to use the first relationships in the form:

$$\tau = \gamma^{a}\dot{\gamma}^{b}[A + B(1 - \frac{T}{T_{\circ}})^{c}]\ .$$

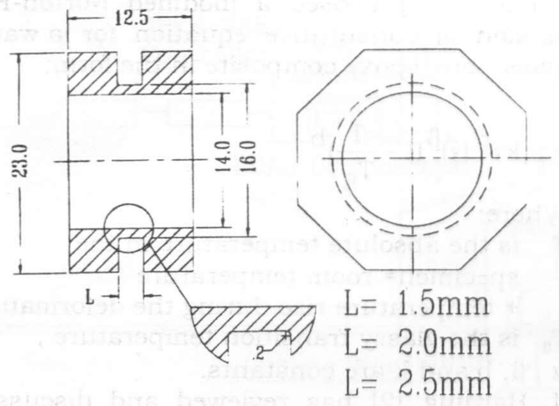

Fig. 4. Specimen dimension.

This for the similarity of the variable parameters (strain rate and temperature) to our case, the coefficients of the formulated constitutive equation was determined on the basis of the experimental results by fitting, using mathcad computer program. Figs. 5-8 shows the test results and the equation values for the 8090-A plate and Figs. 9-12 for 8090MMC-A plate. To get this results we have to consider that the stress strain curves has no failure but has an extended elongation also we well consider only the results of the tests between 100° & 450 °C because the temperature effect is neglected between 25° and 150 °C and the 550 °C is very near to the melting point 650 °C.

If the shear stress in MPa , strain rate in S^{-1} and temperature in degree centigrade the equation parameters will be as follows:

For 8090-A:

A= 49.8 , B= 99.7 , T_o =310 , a= 0.3 , b=0.06 , c= 0.016.

For 8090MMC-A:

A=2676 , B= 973 , T_o =325 , a= 0.493 , b=-0.3 , c= 0.092

6. Results, comments and discussion

The tests have been carried out for each material at six temperature levels (25°,150°, 250°, 350°, 450° and 550°C) and three different strain rate (900, 1500, 2500 S^{-1}) for each plate (A&B); so we have 144 test results. Fig. 13 shows the stress strain diagrams for the 8090-A at different temperatures and at 1500 S^{-1} strain rate, for the same material. Fig. 14 shows the stress strain diagrams at different strain rates at 350°C. Fig. 15 shows the variations of the strength with the temperature of the same material at different strain rates

We can see that in Figs. 5 to 8 for the 8090-A the stress. strain curves have the same shape and the same behaviour. The higher curve is the higher strain rate. The maximum strain before failure is about 0.55 except at temperature 450°C and low strain rates. Also in Figs. 9 to 12 for 8090MMC-A the stress-strain curves have the same shape but are different from those of 8090-A in values and behaviour. They have higher average shear stress and lower maximum strain.

Figure 14 for 8090-A shows that the effect of temperature at the shear strength is fluctuating and have lower values at temperature above 500°C we can see also that the higher strain rate the higher strength. For 8090MMC-A, Fig. 15 shows that the effect of the strain rate is not clear on the shear strength.

7. Conclusions

The 8090 material exhibits a remarkable behaviour at 450°C smaller ductility and higher strength, also the ductility reduced in the lower strain rate . The 8090MMC material shows that the effect of changing temperature and strain rate is not clear on the strength and ductility . It is obvious that 8090 is more ductile and higher in strength than 8090MMC. A similar behaviour of the two materials are shown in the tensile tests results which carried out by Jiang [6] Also. we mention that the negative sign of the factor "b" in the constitutive equation of material 8090MMC show that the effect of strain rate is deferent from that of the 8090.

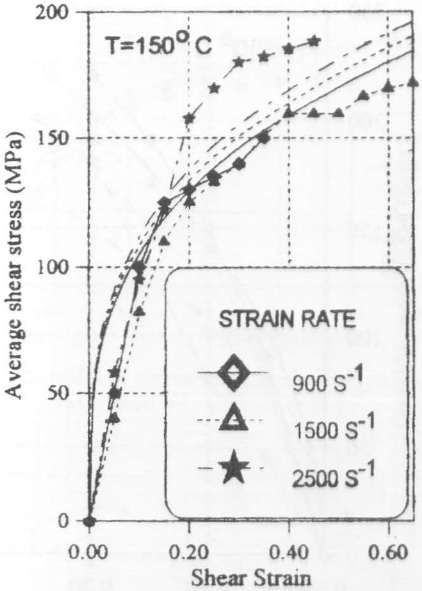

Fig. 5. Fitting to experimental results of 8090-A at 150°C.

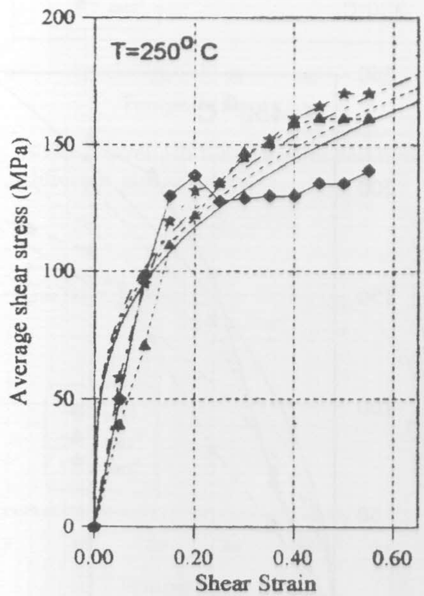

Fig. 6 Fitting to experimental results of 8090-A at 250 °C.

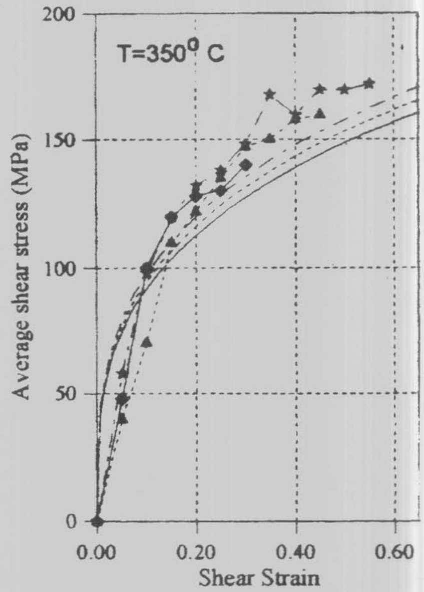

Fig. 7 Fitting to experimental results of 8090-A at 350 °C.

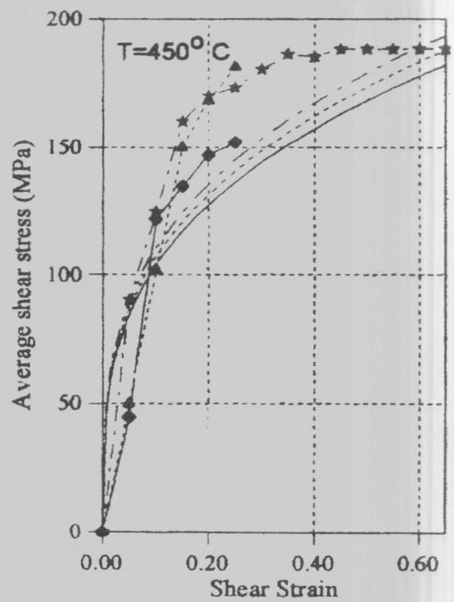

Fig. 8. Fitting to experimental results of 8090-A at 450°C.

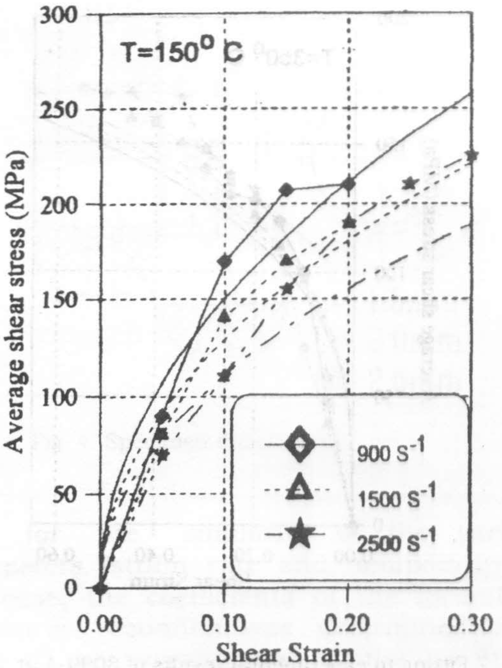

Fig. 9. Fitting to experimental results of 8090MMC-A at 150°C.

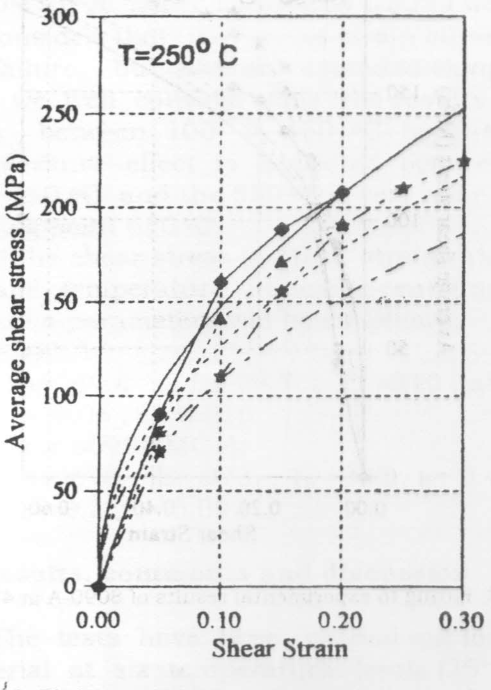

Fig. 10. Fitting to experimental results of 8090MMC-A at 250 °C.

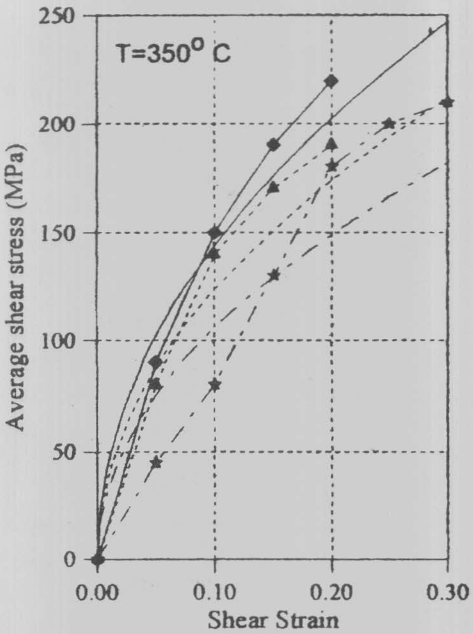

Fig. 11. Fitting to experimental results of 8090MMC-A at 350°C.

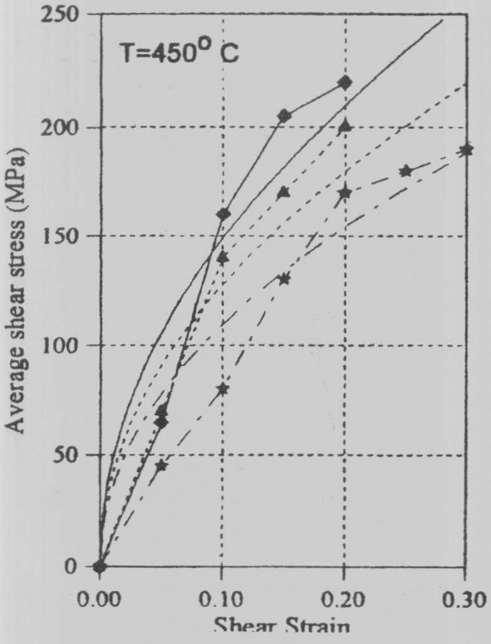

Fig. 12. Fitting to experimental results of 8090MMC-A at 450 °C.

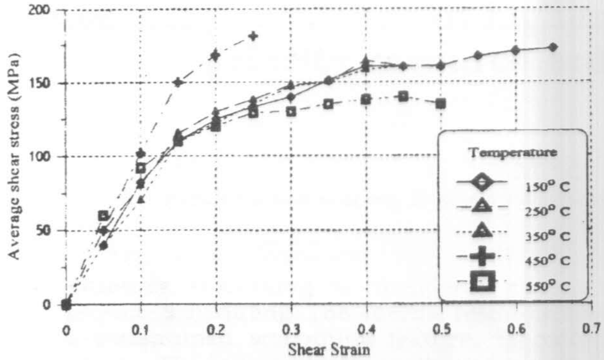

Fig. 13. 8090-A stress strain relations at strain rate 1500 s^{-1}.

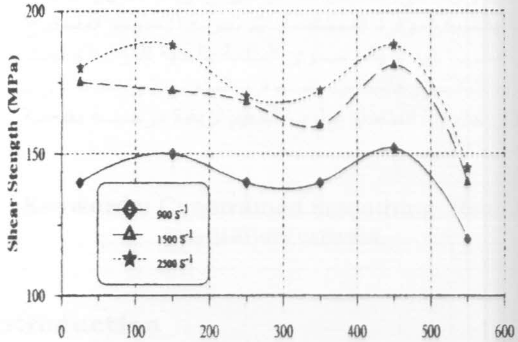

Fig. 14. 8090-A strength temperature relationship at different strain rates.

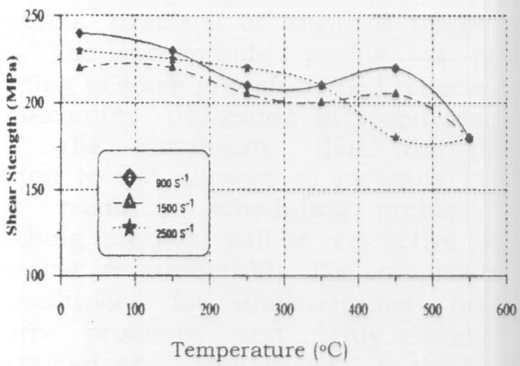

Fig. 15. 8090-MMC-A strength temperature relationship at different strain rates.

Acknowledgement

The experimental work has been carried out at France "ECOLE NATIONALE SUPERIEURE DES ARTS ET METIERS, AVENNE DE L'UNIVERSITE, TALENCE-FRANCE" and the appreciate the support of Prof. J.L. LATAILLADE the head of the group to finish this experimental work.

References

[1] C. Y Chiem, Z. G. Liu," Modelling of Dynamic Behaviour of Composite Materials" Impact Loading and Dynamic Behaviour of Materials, Vol. 2, pp 579-586 (1988).

[2] J. Harding, "The Development of Constitutive Relationship for Material Behaviour at High Rate of Strain" Mech. properties of materials at high rate of strain conference series Number 102, pp. 189-203 (1989).

[3] J. E. Lawson, T. Nicholas, J. Mech. Phys. Solids, 20, pp. 65-76 (1972).

[4] J. L. Lataillade, J.Pouyet, A. Marchand " Caractérisation du Titane T.40 a des Grands Taux de Déformation - Détermination d'une Lui de Comportement Viscoplastique " 2éme partie, Laboratoire de Mécanique Physique, Report Confidentiel S.N.I.A.S. Univ. de Bordeaux I (1982).

[5] M. Schladerer , J. L. Lataillade, J. Pouyet " Conception et realisation d'un banc de torsion dynamique pour l'etude de solides a grand vitesse de deformation" Universitė de Bordeaux 1, Laboratoire de mécanique Physique, Note interne 2 (1981).

[6] Jian Jiang "Mechanical testing of Al-based MMCs with SiCp" DEUR , Interim report-1 November (1991).

Received December 25. 1999
Accepted April 11. 2000