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Fatigue Behaviour of Aluminium Composites Subjected to Surface Mechanical Treatments

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Abstract. This work aimed the evaluation the fatigue behaviour of aluminium matrix composites obtained by powder metallurgy, after a series of surface mechanical treatments. The material was obtained by hot extrusion of powder mixture consisting of aluminium AA 1100 reinforced with 5%, 10% and 15% volume fraction of SiC particles. The fatigue tests were performed in tension-tension mode. All specimens were cycled at a constant stress level. The stress ratio R was 0.1. Machining at different feed rates and shot peening attained the surface finishing. The surface finishing effect on the composite fatigue properties are discussed in terms of number of elapsed cycles versus maximum stress. The results showed great data dispersion. It is demonstrated that coarse machining tends to impair specimens fatigue life when compared to a finer finishing. The increase in the amount of reinforcement is detrimental to the fatigue life. For specimens machined and shot peened, the fatigue life does not show a significant improvement, when compared to other surface finishing.

Introduction

The metal matrix composites (MMCs) have been continuously progressing towards more prosaic uses. These materials show many advantages over monolithic metals, including high specific modulus, high specific strength, enhanced high temperatures properties, low coefficient of thermal expansion, improved wear resistance and toughness properties [1-3]. The development of these materials implies that current methodologies and existent manufacture techniques should be revisited, with the objective of evaluating its applicability. The mechanical forming methods can introduce surface modifications in terms of residual stresses [4,5]. Thus, they can affect the mechanical properties of the materials [6-8].

For monolithic metallic materials, either better surface finishing or surface compressive residual stresses, implies improved fatigue properties [4,9,10]. For metal matrix composite, several works have shown that the presence of the reinforcement may increases the fatigue life. Furthermore, this effect is dependent on matrix strength, interfacial strength and reinforcement morphology [11,12]. Whereas certain parameters such as residual stresses and surface finishing can influence the MMC's mechanical properties, its influence on the fatigue behaviour is still controversial and must be better addressed [13,14].

Experimental

The experiment consisted basically of the elaboration and fatigue testing of three specimens series. Each series was subjected to two variations of mechanical surface treatment - machining and shot peening. A fourth series of control specimens without reinforcement was also prepared for comparison purposes.

The composite material:

The MMC's specimens were extracted from a round bar obtained by hot extrusion of powder mixture, at a reduction rate of 16:1. The matrix consisted of commercial aluminium AA 1100 reinforced with 5, 10 and 15% SiC volumetric fraction. The aluminium and SiC powders had a median particle size of 22 and 6 μm, respectively. The obtention of MMC's by the powder metallurgy route was described elsewhere [15]. The non-reinforced control material was identified as Al/SiC 0%.

The fatigue testing:

The specimen geometry for fatigue testing was chosen according to the ASTM E 466 standard [16]. The axial fatigue testing were performed at a frequency of 15 Hz and stress ratio R = 0.1. The fatigue regime was tension-tension and the testing was done in a servo-hydraulic machine. The specimens were tested in five or six different load levels, according to the yield stress of each material. The fatigue specimens were taken to fracture or the testing was halted at $2x10^6$ elapsed cycles.

Results and discussion

The mechanical properties of the obtained composite materials are presented in the Fig. 1. The microstructure aspects of materials at the longitudinal section are shown in Fig. 2.

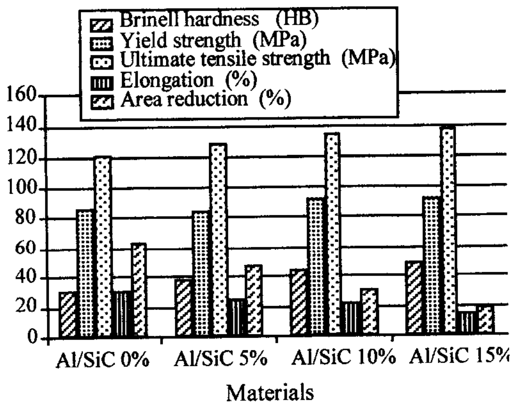

Fig. 1. Mechanical properties of the aluminium composite materials used in this investigation.

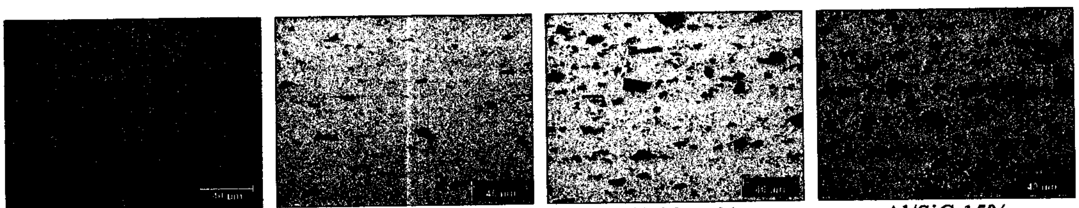

Fig. 2. Optical micrographs of the aluminium composite materials obtained by powder metallurgy showing the SiC particles distribution.

Table 1 shows the specimens separated by series, with the respective methods of applied surface mechanical treatments, machining at different feed rates and shot peening. Figs. 3 a -c and 4 a-c show the general aspects of the longitudinal section profiles and the surface. The surfaces mean roughness (RA) measured in the gage lengths of the prepared fatigue testing specimens are show in Fig. 5.

Table 1. Composite fatigue specimens grouped according to the applied surface mechanical treatment.

Series	Material	Machining and shot peening conditions
	Al/SiC 5%	(A) PCD machined
1	Al/SiC 10%	(f: 0.06 mm/rot)
	Al/SiC 15 %	
	Al/SiC 5%	(B) PCD machined
2	Al/SiC 10%	(f: 0.24 mm/rot)
	Al/SiC 15 %	
	Al/SiC 5%	(C) PCD machined
3	Al/SiC 10%	(f: 0.06 mm/rot)
	Al/SiC 15 %	and shot peened
		(A) PCD machined
4	Al/SiC 0%	(f: 0.06 mm/rot)

PCD polycrystalline diamond tool, f: feed rate

Fig. 3a. Profile section of Al/SiC 5% according to A (Table 1).

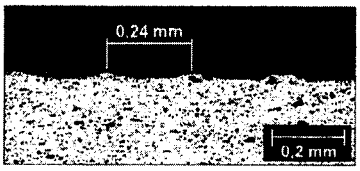

Fig. 3b. Profile section of Al/SiC 5% according to B (Table 1).

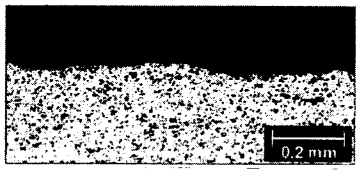

Fig. 3c. Profile section of Al/SiC 5% according to C (Table 1).

Fig. 4a. Surface of Al/SiC 5% according to A (Table 1).

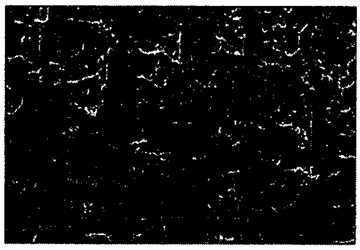

Fig. 4b. Surface of Al/SiC 5% according to B (Table 1).

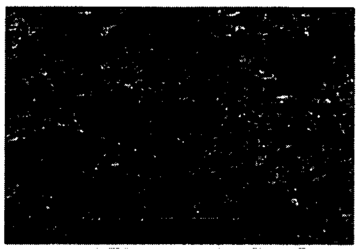

Fig. 4c. Surface of Al/SiC 5% according to C (Table 1).

Fatigue life

The fatigue life of the materials reinforced with 5% of SiC (Fig. 6) showed an accentuated concentration of the curves for each preparation condition. The shot peened specimens presented an inferior behaviour when compared to the machined specimens with feed rate of 0.06 mm/rot and practically equal to the coarse machined (feed rate of 0.24 mm/rot). These results agree with Oman et al and Bathias [13,14] findings, indicating that the compressive residual stress produced by shot peening is not capable of compensating the strongly degraded surface resulting from the machining (see Fig. 3c).

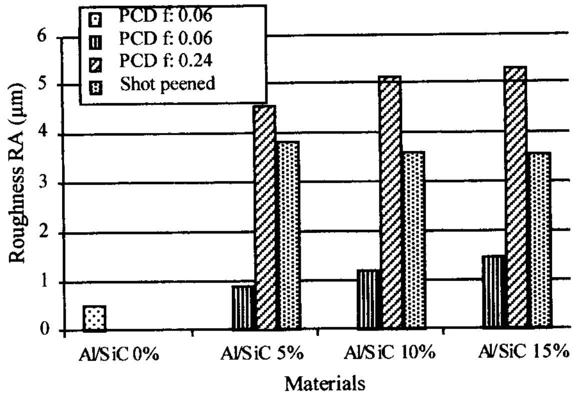

Fig. 5. Surface mean roughness of the composites specimens with different volume fraction of SiC.

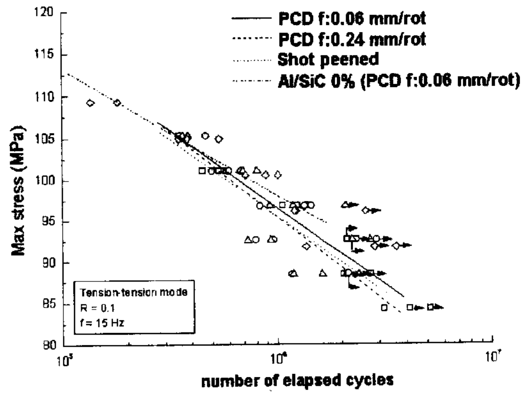

Fig. 6. Fatigue curve of the composite Al/SiC 5%, after different surface treatment.

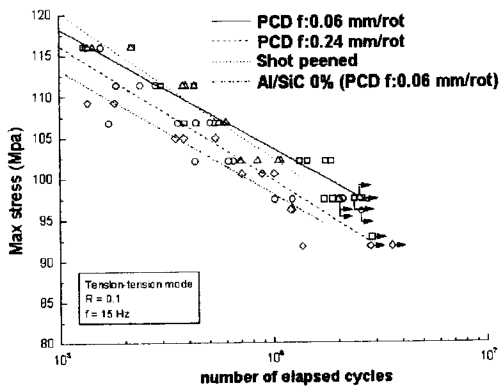

Fig. 7. Fatigue curve of the composite Al/SiC 10%, after different surface treatment.

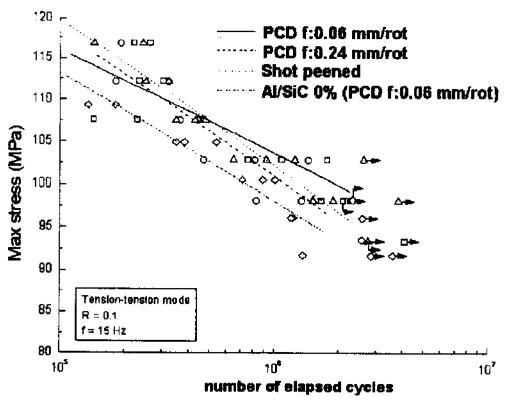

Fig. 8. Fatigue curve of the composite Al/SiC 15%, after different surface treatment.

For the Al/SiC 5% composite, the unreinforced material presented a better fatigue life with relation to those reinforced, see Fig. 6. Bathias, Masuda and Tanaka, Bonnen et al [14,17,18], agreed in the sense that, the fatigue life is only improved when the reinforcement volumetric fraction is between 10 and 20%, depending on the technique used for the material obtention. Harris [19] observed that the fatigue life was reduced with the incorporation of reinforcement phases. These materials involved reinforcements fraction of the order of 20% and consequently, it may also be related to the conclusions of matrix saturation already expressed [14,17,18]. Although it has not been found reference approaching fatigue in composites with 5% of reinforcement, from the results obtained in this work, there are circumstantial evidences of a minimum reinforcement volume fraction, whose benefits in terms of fatigue behaviour are not observed. An evidence of the previous proposition is the fact that the non-reinforced material of this work, presented a higher yielding limit than the Al/SiC 5% (see Fig. 1). Under these circumstances, the type of surface mechanical treatment used, had little or insignificant influence in the fatigue life of this material.

The composites reinforced with 10 and 15% of SiC (Fig. 7 and 8) presented scattered fatigue curves, showing that the specimens machined with feed rate of 0.06 mm/rot, competes with the shot peened in terms of fatigue life. It is clear that the shot peening is beneficial for lower fatigue cycling i.e., for stresses above 105 MPa and the fine-machined specimens showed a better fatigue behaviour below this value. In both cases, for 10 and 15% of SiC, there was no significant fatigue life improvement for the shot peened specimens with relation to the machined samples.

The coarse machined specimens (feed rate of 0.24 mm/rot), presented worse fatigue life in all cases. The machining tools grooves left on the specimens surface (Figs. 3b and 4b for Al/SiC 5%), worked as strong stress concentrators, whose roots showed preferential sites for fatigue crack initiation (Fig. 9 for Al/SiC 10%). For the coarse machined material the incidence of fatigue cracks was higher than in the fine machined and the shot peened specimens. For the fine-machined materials, it was not possible to visualise the grooves left by the machining tool, hence it is not possible to establish its effect as in the case of the coarse machined material.

Surface roughness

Analysing the roughness of the shot peened specimens and coarse machined (Fig. 5) it is possible to confirm once more the observations of Oman et al and Bathias [13,14], that have credited the degradation of the surface to the shot peening. Notice that the surface roughness attained in the two treatments - coarse machining and shot peening - are practically of the same order, but the benefits of the present shot peening conditions are not so impressive.

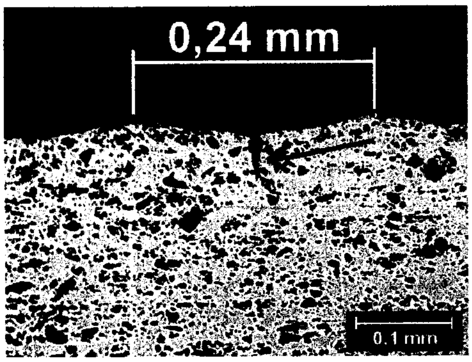

Fig. 9. Section profile of a Al/SiC 10% specimens, machined at a feed rate of 0.24 mm/rot, taken from a region next to the fatigue fracture. The arrow indicates a fatigue crack at the machining root.

Relationship between the reinforcement volumetric fraction and the surface finish.

Through the analysis of Figs. 6, 7 and 8, it is possible to note that the material reinforced with 5% of SiC presented less sensibility to fatigue (slope of load variation versus number of elapsed cycles curve) for all the types of surface mechanical treatments, when compared to the materials reinforced with 10 and 15%. For the materials reinforced with 10 and 15% of SiC, the machined specimens with feed rate of 0.06 mm/rot presented a higher fatigue sensibility to the load variation. The coarse-machined material presented the worse fatigue life, however showing smaller fatigue sensibility.

The variation of 5 to 10% of SiC reinforcement caused an increase of the fatigue sensibility for all the surface mechanical treatments used. With the increase of 10 for 15%, it is noticed that the sensibility stays practically unaffected for the coarse machined and shot peened materials. For the machined materials with feed rate of 0.06 mm/rot, however, there was a quite significant sensibility increase.

Conclusions

- The fatigue life of the material reinforced with 5% of SiC was inferior to the unreinforced for all types of surface treatments used. This behaviour can be attributed to the fact of this material presented a lower yielding strength than the unreinforced material. Under these circumstances, the type and conditions of surface mechanical treatment used, had small or insignificant influence in the fatigue life.

- The grooves caused by coarse machining were quite visible and they acted as strong stress concentrators originating fatigue cracks.

- All surface mechanical treated specimens, presented the same fatigue sensibility with the variation of the load (slope of the fatigue curve), for each type of tested composite, except for Al/SiC 15% machined with feed rate of 0.06 mm/rot that showed a quite accentuated difference.

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