FATIGUE CRACK GROWTH OF AL-SiC$_P$ METAL - MATRIX COMPOSITES

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The purpose of this paper is to attempt to establish correlation between the varying contents of Mg and SiC$_p$, and the fatigue crack resistance of the composite. The casted Al alloy was used as matrix, with 3, 5 and 7 % of Mg. Contents of the reinforcement, SiC particles were 2, 5 and 10 %. The size of the particle was 30 μm. The results of the mechanical properties, crack resistance and fatigue tests, performed for all mentioned combinations of Al matrix alloy and percentage of reinforcement, are presented. The obtained results of tensile tests, Charpy V impact tests and crack growth rate da/dN vs. ΔK is discussed and compared for each case of varying content of Mg and different content of SiC$_p$.

INTRODUCTION

In recent years Al-SiC$_p$ metal matrix composites (MMC) have been introduced because of their superior mechanical properties such as combination of high stiffness, high strength and good tribological properties with low density and potentially low unit cost. It is well known that there are several problems regarding fabrication of this class of composites due to wettability and dispersion of SiC particles with molten matrix (1,2,3,4). Also, a variety of factors influence the microstructure and properties of cast Al-SiC$_p$ composites (2). This paper reports the influence of varying Mg and SiC$_p$ content on fatigue crack growth.

Material Description

The matrix alloy used in this research is the Al with different content of the Mg. The chemical composition of the used matrix alloy is presented on Table 1. The composition of the reinforcement is presented on Table 2.

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The size of the particle was 30 μm. The composite was obtained by adding SiC particles into the melted matrix material, kept at certain temperature (proprietary information). The composite was initially cast, by vortex method, in ingot form. The ingots were die cast into blocks, from which specimens used in this research were made. Stirring of mixture was applied during the casting to avoid particle clustering. Post heat treatment was not applied on casted ingots.

TABLE 1- Composition of the matrix alloy, mass %

Matrix	Mg	Mn	Si	Fe	Ti	Zn	Cu	Al
AlMg3	2,90	0,30	0,050	0,18	0,055	0,10	-	rest
AlMg5	4,95	0,35	0,045	0,12	0,035	0,12	-	rest
AlMg7	7,05	0,63	0,081	0,23	0,051	0,030	0,001	rest

TABLE 2- Composition of the reinforcement, mass %

C	$Si+SiO_2$	TiO_2	FeO_3	Al_2O_3	CaO	MgO	SiC
0,12	1,88	0,14	0,50	0,14	0,13	0,04	96,65

Chosen contents of reinforcement are unusual (2), that is, too low to produce the significant strengthening. Basic idea was to produce inexpensive MMC with good resistance to fatigue crack growth.

EXPERIMENTAL PROCEDURES

The following experiments were performed on specimens made of the MMC:

- monotonic tensile loading to determine the material elasticity modulus, E, ultimate tensile strength, S_{ut} and strain to fracture, ε_f ;
- impact testing to determine impact energy;
- fatigue crack growth testing.

Rectangular die cast blanks, 65 by 160 by 15 mm were used for all specimens. All tests were performed at room temperature (20°C on average).

Monotonic loading

The dimensions of tensile specimens and load rate were chosen in accordance with ASTM E8-89. Results of tensile testing are presented on Fig. 1 to Fig 3.

Impact testing

The dimensions of Charpy specimens for impact testing were chosen in accordance with ASTM E23-86. Impact testing was performed on instrumented pendulum. Results of impact testing are presented on Fig. 4 and Fig 5.

Fatigue Crack Growth

The fatigue crack growth tests at room temperature were performed under wave form (three points bending) constant amplitude load control on Charpy specimens. All tests were performed under the same ratio of minimal and maximal load, R=0,1. Accuracy of acquisition of the average load and amplitude was ±5Ncm and frequencies were in range of 175-195 Hz. Results of da/dN vs. ΔK are presented on Fig. 6 to Fig 8.

Paris-Erdogan equation parameters and threshold values, C, n and ΔK_{th} obtained from da/dN vs. ΔK curves are presented in Table 3.

TABLE 3- Results of values for ΔK_{th} , C and n, for all combinations of matrix alloy and reinforcement

MMC	R	C	n	ΔK_{th}, MPa $m^{1/2}$
AlMg3 - 2% SiC	0,1	$3{,}92 \cdot 10^{-15}$	9,301	3,81
AlMg3 - 5% SiC	0,1	$7{,}28 \cdot 10^{-15}$	8,861	3,95
AlMg3 - 10% SiC	0,1	$5{,}46 \cdot 10^{-16}$	10,845	4,05
AlMg5 - 2% SiC	0,1	$5{,}18 \cdot 10^{-15}$	8,027	4,05
AlMg5 - 5% SiC	0,1	$7{,}45 \cdot 10^{-14}$	7,065	4,10
AlMg5 - 10% SiC	0,1	$6{,}49 \cdot 10^{-15}$	8,181	4,13
AlMg7 - 2% SiC	0,1	$7{,}26 \cdot 10^{-17}$	12,421	3,95
AlMg7 - 5% SiC	0,1	$5{,}69 \cdot 10^{-16}$	10,679	3,95
AlMg7 - 10% SiC	0,1	$6{,}28 \cdot 10^{-16}$	10,426	4,20

DISCCUSION

In Fig. 1, Fig 2 and Fig 3, observed scattering of all data can be explained with noted porosity of the obtained casted blocks. This scattering is especially visible for the strain to failure data, Fig 3. From the monotonic tensile load tests, the conclusions can be drawn that the best results were with AlMg5-10%SiC_p combination.

Impact testing results presented on Fig. 4, show that the minimum scattering is observed on AlMg5-10%SiC_p. The sum values were the highest on AlMg7-10SiC_p. Same is on Fig. 5. for the values on crack initiation and crack propagation, during impact testing.

Fig.6 to Fig 8. and Table 3. show that the growth rate of fatigue cracks is the greatest with AlMg5-10%SiC_p. Scattering and deflection of curves, in region II, from Fig.6 to Fig.8 can be explained by non-uniformly distribution of reinforcement in all matrix alloys. With cracks propagation through region poor with reinforcement, crack closure effect was observed. Same was confirmed by fractography analysis. For the binary matrix system, Al-Mg, it is known that with increasing Mg content, portion of β phase, after 5% of Mg, significantly expands presence in the matrix. This is confirmed by EDX analysis. The significant influence, during SEM analysis, of the β phase as crack initiation site is not observed. Virtually all crack initiation sites were on SiC-matrix interface (5,6).

CONCLUSIONS

The results of presented tests indicate that:

- Porosity and non-uniformity of SiC_p produced a scattering of the values of Young modulus, ultimate tensile strength, strain to failure and impact energy.
- The ΔK_{th} values are not significantly influenced with Mg content and portion of SiC_p.
- Crack closure effects were pronounced, for all combinations of MMC, especially in Region II, due to non-uniformity of SiC particles.
- Fatigue crack growth rate is the lowest for AlMg5%-10SiC_p combination, for presented route of producing MMC.

SYMBOLS USED

E	-	Young's modulus, GPa
S_{ut}	-	Ultimate tensile strength, MPa
ε_f	-	Strain to fracture, %
ΔK_{th}	-	Threshold value, MPa $m^{1/2}$
C, n	-	Paris-Erdogan equation parameters

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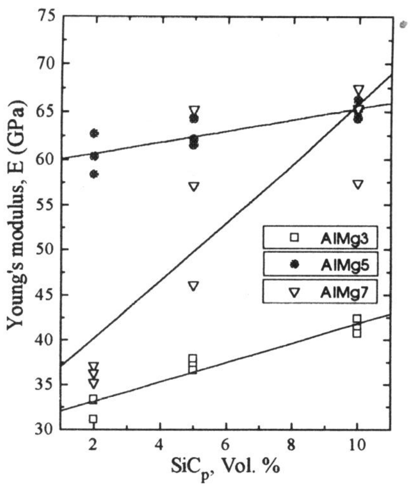

Figure 1. Young's modulus vs. Vol. % of SiC_p

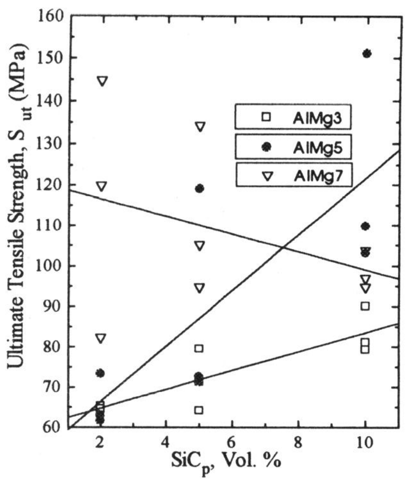

Figure 2. The ultimate tensile strength vs. volume percent of SiC_p

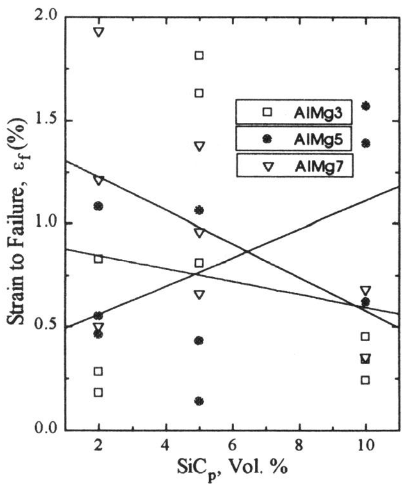

Figure 3. Strain to failure, ε_f vs. volume percent of SiC_p reinforcement

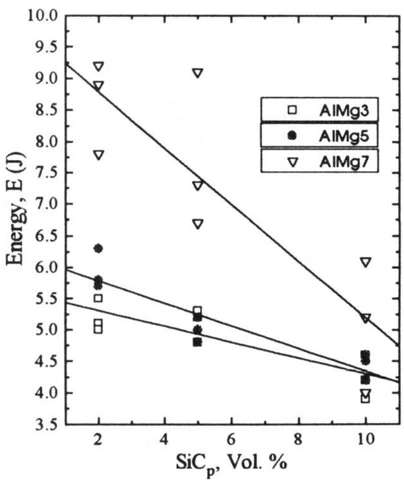

Figure 4. Impact energy vs. volume percent of SiC_p reinforcement

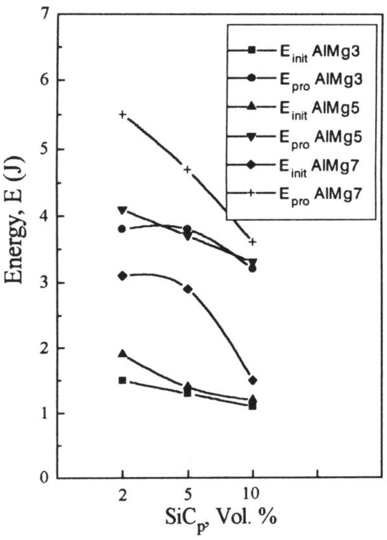

Figure 5. Initiation and propagation impact energies for all MMC

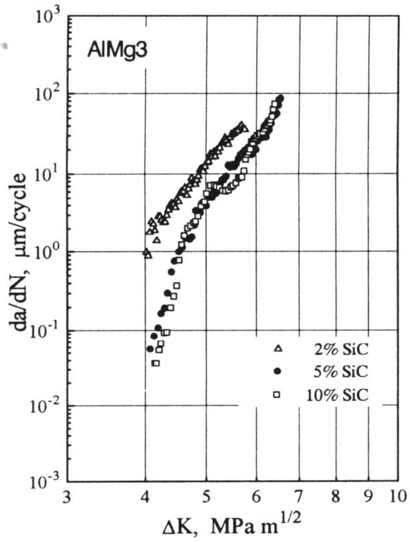

Figure 6. Relation between da/dN vs. ΔK for AlMg3 matrix alloy

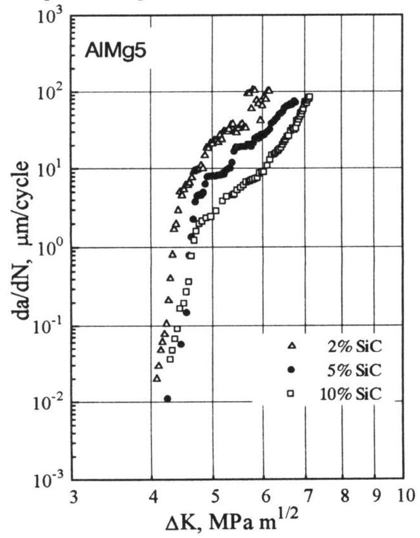

Figure 7. Relation between da/dN vs. ΔK for AlMg5 matrix alloy

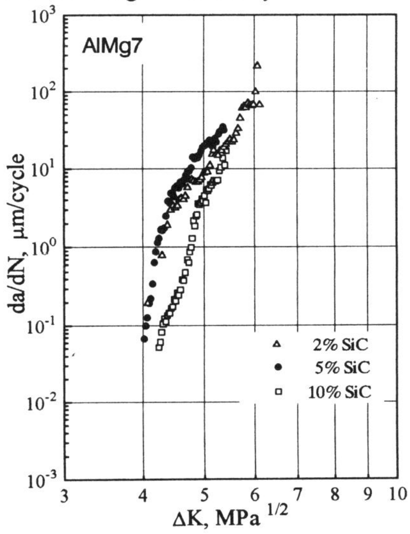

Figure 8. Relation between da/dN vs. ΔK for AlMg7 matrix alloy