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Influence of combined relaxation, creeping and low-cycle fatigue on the final durability and structure of material

Dissertation

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ABSTRACT

There is growing interest in developing more advanced materials that are cost-effective, lightweight, and durable, as conventional materials are unable to meet the demands of the automotive, aerospace, and military industries. Studying the mechanical properties of these materials is essential to enhance their suitability for demanding industries and ensure that they can withstand high stress under harsh environmental conditions. To meet the needs of these sectors, the use of advanced materials with superior properties is important. For this study, aluminium metal matrix composites (AMMCs) were chosen as they are promising advanced engineering materials with improved properties. AMMCs are notable in engineering applications due to their enhanced mechanical properties compared to conventional aluminium alloys. These advanced materials hold great promise for high-precision applications in various engineering industries. Aluminium metal matrix composites find essential applications in different technological fields. These materials have been developed to improve their strength, abrasion resistance, rigidity, creep resistance, and dimensional stability. Metal matrix composites (MMCs) using aluminium alloy as a base material have gained significant traction in the aerospace and automotive sectors due to their extensive and ubiquitous use.

However, the combination of complex loading and high temperatures significantly affects the durability of these materials. Creep and fatigue failures are more likely to occur when materials are subjected to cyclic load and elevated temperature. In this research work, experimental investigations were used to characterize the material behaviour of AMMC and its matrix alloy at elevated temperatures. Initially, uniaxial tensile tests were performed at room and elevated temperatures to assess the mechanical properties of the material. The hardness measurements were

also conducted to evaluate the hardness of both composite and matrix alloy. Light microscopy and scanning electron microscopy were used to analyze the structure of the material.

The results of the microstructural analysis show that the SiC particles are uniformly distributed in the matrix. The results of the experimental tests indicate that the tensile properties and hardness of the EN AC-Al Si12CuNiMg/10SiCp composite are significantly higher than those of the unreinforced eutectic alloy. For EN AC-Al Si12CuNiMg/10SiCp composite, the tensile strength is 21%, the yield strength is 16%, the modulus of elasticity is 20%, and the hardness is 11% higher than the unreinforced matrix alloy. However, the unreinforced EN AC-Al Si12CuNiMg alloy has a percentage elongation of 16% higher than the composite material. This shows that the EN AC-Al Si12CuNiMg/10SiCp composite has a lower ductility than the unreinforced EN AC-Al Si12CuNiMg alloy. The tensile specimens of the tested composite broke apart in a brittle manner with no discernible neck development, in contrast to the matrix specimens, which broke apart in a ductile manner with very little discernible neck formation.

The study reveals that the combination of fatigue and creep loading significantly reduces a material's fatigue life. The fatigue-creep loading sequence results in a 65% decrease in the number of cycles to failure compared to the full fatigue test. The material experiences more significant deformation during creep loading stages than during fatigue loading stages, especially when subjected to constant stress equal to the maximum cyclic stress level for an extended period. The combination of fatigue and creep loads accelerates material deterioration through mechanisms such as crack propagation and grain boundary degradation, resulting in a reduced service life. The fatigue-stress relaxation sequential loading test results show a 60% reduction in the material's durability due to the combined effect of fatigue and stress relaxation loading.

Fracture surface analysis of the Al-Si/SiCp composite shows fatigue fractures, primarily due to the debonding of the particle-matrix interfaces at elevated temperatures. The study examines the fracture behaviour of Al-Si/SiCp composite samples after creep loading at 250°C. The high temperature softens the Al-Si matrix, leading to microstructural changes that weaken the interface between SiC particles and the matrix, accelerating the degradation of the composite. SEM analysis reveals an intergranular fracture mode, cavities, and voids on the fracture surface, indicating localized deformation and stress accumulation. The composite has a combination of brittle and ductile properties, with ductile behaviour being dominant during the fracture process. Fatigue-creep loading leads to a higher degree of intergranular fracture and a higher density of secondary cracks, indicating a more complex failure mechanism. The material undergoes both ductile and brittle fracture processes under both fatigue creep and fatigue relaxation loading sequence. In general, the study presents the significant reduction of durability under fatigue-stress relaxation and fatigue-creep loading sequence.