International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Computer Aided Analysis of Aluminum Metal Matrix Composite with Al_2O_3 Particle Addition

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Doi: https://doi.org/10.55248/gengpi.5.1124.3217

Summary

In this study, computer-aided analysis of Al2O3 particle reinforced aluminum metal matrix composites is discussed. Tensile and fatigue tests were performed using ANSYS software.

Al2O3 particle reinforced aluminum matrix composites are preferred materials in many industrial applications due to their advantages such as high strength, light weight and good thermal conductivity. In this study, the potential of Al2O3 particles to improve the mechanical performance and durability of these composites is investigated.

First, the geometry and material properties required for the analysis were defined and appropriate boundary conditions were determined to accurately simulate the behavior of the specimen. Tensile and fatigue tests of the specimen were modeled in ANSYS.

The tensile test was performed to evaluate the mechanical strength of the specimen. Using ANSYS, the tensile test conditions of the specimen were simulated and the stress-deformation behavior was analyzed. This analysis was performed to determine the elastic and plastic behavior of the composite, stress distribution and fracture point.

Fatigue testing was carried out to evaluate the behavior of the specimen under repetitive loads and fatigue life. Using ANSYS software, the fatigue test conditions of the specimen were simulated and the stress-cyclic deformation behavior was analyzed. This analysis was performed to examine the fatigue durability of the composite.

This study helps us to understand the mechanical behavior and durability of Al2O3 particle reinforced aluminum metal matrix composites by examining in detail the results of tensile and fatigue tests performed using ANSYS software. The findings can be applied in many areas such as material design, manufacturing and performance improvement and can serve as a basis for future studies.

Keywords: Al2O3, particle reinforced, aluminum metal matrix composite, computer aided analysis, ANSYS program, tensile test, fatigue test, mechanical performance, durability.

1.Introduction

Nowadays, the demand for materials with superior properties such as light weight, high strength and good thermal conductivity is increasing rapidly. In order to meet this demand, composite materials have been developed in the field of materials engineering using various reinforcing materials. Aluminum oxide (Al2O3) particles are a widely used reinforcing material, especially to improve the mechanical performance and durability of aluminum metal matrix composites.

Aluminum metal matrix composites reinforced with aluminum oxide (Al2O3) particles are of increasing interest in engineering applications. These composites offer unique performance advantages by combining the light weight and strength of aluminum with the superior properties of Al2O3, such as hardness and wear resistance. The dispersion of Al2O3 particles into the aluminum matrix significantly improves the mechanical properties of the composite, making them ideal materials in various industries such as automotive, aerospace and construction. In particular, such composites exhibit properties such as high strength-to-weight ratio, good thermal and electrical conductivity, corrosion resistance and superior wear resistance.

Various methods are used in the production of Al_2O_3 reinforced aluminum metal matrix composites. Among these, techniques such as casting, powder metallurgy, and friction stir processing (FSP) are prominent. Each of these methods has its own advantages and disadvantages.

Casting Method: In this method, Al_2O_3 particles are added into the molten aluminum and a homogeneous distribution is achieved, resulting in a composite material. The advantage of the casting method is that it is suitable for large-scale production.

Powder Metallurgy: In this technique, aluminum and Al_2O_3 powders are mixed, compacted and sintered. This method provides higher homogeneity and controllable microstructure.

Friction Mixing Method: This modern method ensures homogeneous distribution of Al_2O_3 particles on aluminum sheets and improves mechanical properties.[1]

In the literature, there are many studies on various production methods, microstructure and mechanical properties of Al2O3 reinforced aluminum metal matrix composites. These studies examine how the manufacturing parameters of the composites, reinforcement particle size, distribution and volume fraction affect the mechanical properties of the composite.

Microstructural characterization studies examine the effects of factors such as particle distribution, particle-matrix interfacial bonding and the presence of second phases on the properties of composites. Particle distribution and particle-matrix interfacial bonding have been shown to significantly affect the mechanical behavior of composites.

In terms of mechanical properties, aluminum metal matrix composites reinforced with Al2O3 particles are known to have higher strength and hardness values compared to pure aluminum. However, as the particle volume fraction increases, the toughness and ductile behavior of the composites decrease. Therefore, the particle volume fraction and distribution should be kept at optimum values to achieve the desired mechanical properties.

In terms of tribological properties, it was observed that aluminum metal matrix composites reinforced with Al2O3 particles exhibited better wear resistance than pure aluminum. This is attributed to the particles inhibiting oxidation on the wear surface and modifying the wear mechanism.

However, it is important to note that most of the studies in the literature have been carried out at laboratory scale and more research is needed in industrial scale production and application. Furthermore, issues such as the cost-effectiveness and recycling potential of Al2O3-reinforced aluminum metal matrix composites need to be further investigated.

Computer-aided analysis is an important tool for evaluating the behavior and performance of Al2O3 particle reinforced aluminum metal matrix composites. These analyses are used to determine the mechanical properties, strength, stress distribution and fracture points of the material. Computer-aided analyses are usually based on numerical methods such as the finite element method and are performed through numerical simulation software.

In this study, computer-aided analysis of Al2O3 particle reinforced aluminum 6061 metal matrix composites is discussed. Particular emphasis is placed on tensile and fatigue tests performed using ANSYS software. Tensile testing is used to evaluate the elastic and plastic behavior of the material, stress-deformation relationship and fracture points, while fatigue testing examines how the material behaves under repetitive loads and fatigue life. We will focus on the microstructural and mechanical properties of Al2O3 particle reinforced aluminum metal matrix composites and present experimental and numerical analyses to determine the performance of these materials. The results obtained can be used to optimize the design of these composites, improve their manufacturing processes and identify their potential applications. Furthermore, this study will provide the basis for future research and contribute to advances in the field of mechanical engineering.

2. Materials and Methods

The materials used in this study are composites based on 6061 Aluminum alloy metal matrix. With Al2O3 particle reinforcement to this metal matrix, 10 wt% Al2O3 metal matrix composite material was obtained.

2.1 Tensile Test Specimen and Tensile Test

Powder Mixing: A process was carried out where 6061 Aluminum powder (particle size less than 63 µm) and Al2O3 powder (average particle size 0.7 µm) were mechanically mixed. This mixing process was carried out in an argon atmosphere using a planetary mill. Citric acid was added at 0.5% by weight of the powder mixture to avoid excessive coalescence during grinding.

Compaction: After the process of mechanically stirring the powder mixture, this mixture was compacted to have a homogeneous distribution of Al2O3 in the aluminum matrix. Uniaxial compression was used to consolidate the powder and a pressure of 200 MPa was applied in this process.

Degassing: The compacted disks probably served as starting material for further processing. These disks were subjected to degassing by heating to 400°C to remove any lingering gas or impurities.

Extrusion: The degassed disk was then subjected to extrusion. This process involves passing the material through a die to create a new shape or form. In this case, the diameter of the material was reduced from 76 mm to 17 mm. The extrusion process was carried out at a temperature of 550°C.[2]

2.1.2 Performing the Tensile Test

The Instron 8801 materials testing system was used to obtain tensile test results. This testing system is a closed-loop servo-hydraulic, dynamic, single-axis testing system. The machine is equipped with a hydraulically operated self-aligning gripping system and a photograph of the testing machine is shown in Figure 1.

In accordance with ASTM E8m, cylindrical specimens for tensile testing were machined with the stress axis parallel to the extrusion direction. Uniaxial tensile tests at room temperature were performed on an 8801-test machine. A strain gauge was installed to measure the failure stress of the specimens. At least 3 specimens were tested to obtain an average value. The diameter speed of the test was set to 3 mm/min for all specimens (Figure 1).[2]

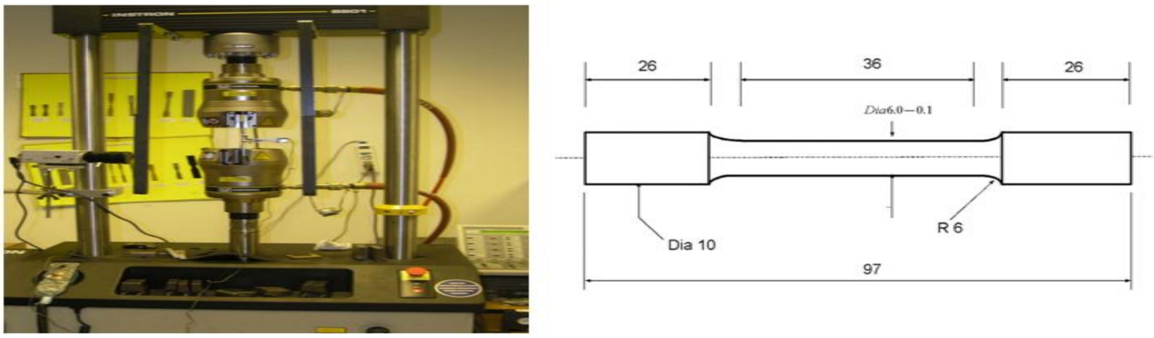

Figure 1. Tensile test setup and tensile specimen

2.1.3 Tensile Test Results

According to the tensile test results performed with the Instron 8801 material testing system, 0.2% yield strength was determined as 180(MPa), tensile strength 326.11(MPa), young's modulus 78.48(GPa), plastic elongation 6.26(mm) [2].

2.2 Fatigue Test Specimen and Fatigue Test

The preparation of 6061Al/Al2O3 composites was carried out using the stir casting method. In this process, the Al2O3 particles used as reinforcement were preheated to 200°C before being added to the molten metal. Al2O3 nanoparticles with a grain size of 50 nm were used as reinforcement particles. The stirring speed was set at 450 rpm and the casting temperature was fixed at 850°C. As a result of these processes, a nanocomposite containing 10%Al2O3 was obtained in the form of a cylindrical rod with a length of about 100 mm and a diameter of 12 mm.[3]

2.2.1 Fatigue Testing

A Schenck product-type rotary bending machine was used to perform all fatigue tests, including constant and variable amplitude fatigue tests. The fatigue specimen shown in figure () has a round cross-section and is subjected to bending moment by a load perpendicular to the axis of the specimen. The experimental setup is shown in figure 2.[3]

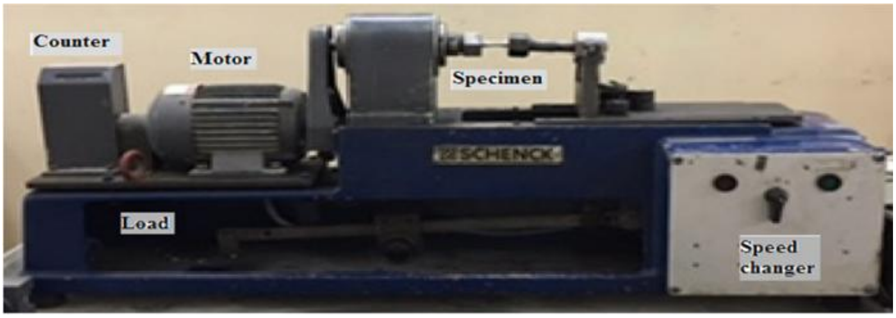

Figure 2. Fatigue test setup

2.2.2 Fatigue Test Results

S-N curves were generated for Al 6061 metal matrix and Al 6061-10 wt% nanocomposite specimens under constant amplitude fatigue stress. The S-N curves are shown in Figure 3. The results show that the Al6061-10 wt% nanocomposite has a higher fatigue strength than the Al6061 metal matrix. This observation suggests that Al2O3 nanoparticles improve the fatigue properties of the composite material.[3]

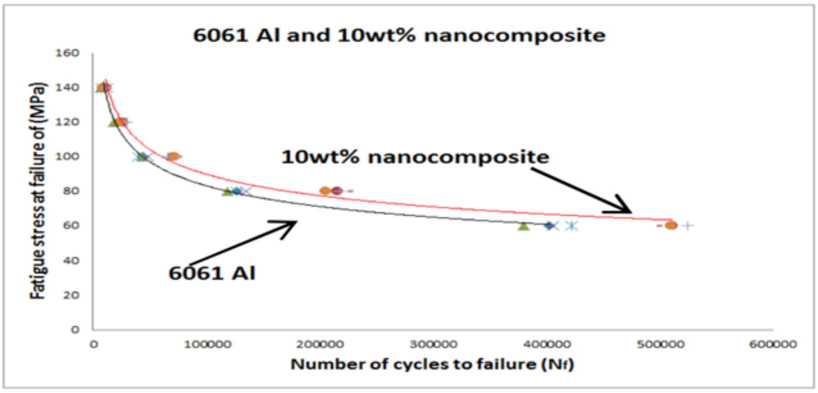

Figure 3. S-N curves

3. RESULTS

3.1 Tensile Test Model Creation and Analysis in Ansys

The first step in the simulation process is the creation of a CAD (Computer Aided Design) model with the material properties and geometry required for the tensile test. This model represents the environment in which the test will be performed and the geometry of the material to be tested. To create a CAD model, the dimensions and geometry of the material to be tested must first be determined. This information should be transferred to the model to reflect the actual properties of the material. The simulation is performed by specifying the meshing process and boundary conditions to the created CAD model. Figure 4 shows the CAD model, meshing process, boundary conditions (fixed region and load region).

Material properties include values such as Young's Modulus, yield strength of 0.2% and ultimate tensile strength, which define the material elasticity. These properties are critical to understanding the behavior and durability of the material. Accurate determination of material properties from laboratory tests or data obtained from the literature ensures that simulation results match real-world conditions. Therefore, careful specification of material properties prior to simulation, based on up-to-date data, is an essential step for a successful tensile test analysis. The material information is shown in Figure 5.

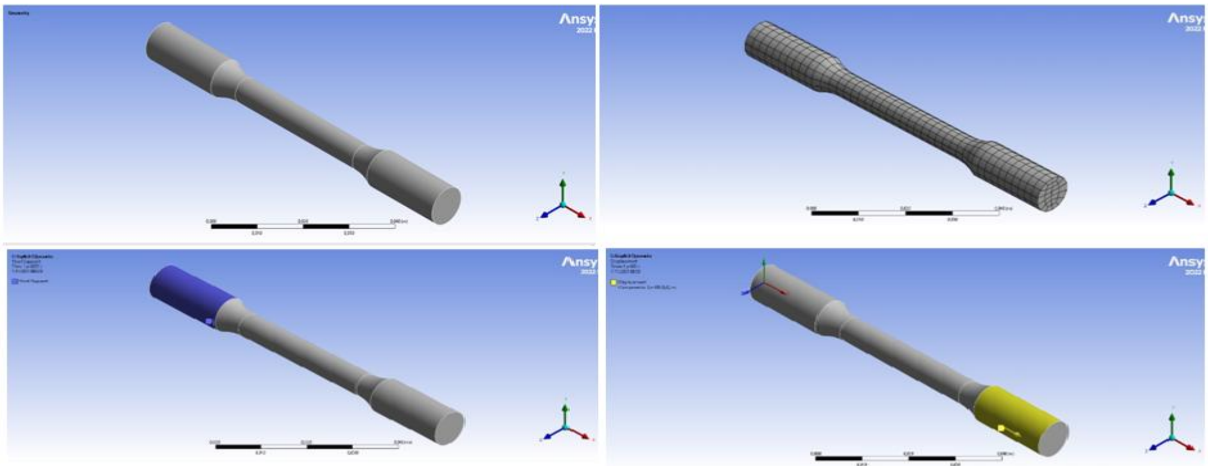

Figure 4 a) cad model b) mesh process c) fixed region d) load region

Properties of Outline Row 3: al2o3

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2,87	g cm^-3		
4	Isotropic Elasticity				
5	Derive from	Young's ...			
6	Young's Modulus	78,48	GPa		
7	Poisson's Ratio	0,33			
8	Bulk Modulus	7,6941E+10	Pa		
9	Shear Modulus	2,9504E+10	Pa		
10	Tensile Yield Strength	180	MPa		
11	Tensile Ultimate Strength	326,11	MPa		
12	Specific Heat Constant Pressure, C_p	897	J kg^-1 ...		
13	Johnson Cook Strength				
22	Specific Heat Constant Volume, C_v	897	J kg^-1 ...		

Figure 5. Material information

3.1.2 Johnson Cook Parameters

The Johnson-Cook material model is a material model that mathematically describes the plastic deformation behavior under high energy effects. This model is used to simulate material behavior by considering the plastic yield strength of the material, temperature effects and deformation rates. The Johnson-Cook model uses various parameters to calculate how material strength changes with temperature, velocity and stress. These parameters must be determined experimentally for a specific material and are intrinsic to the properties of the material.

Johnson-cook parameters are calculated using the stress-strain graph of the composite material being tensile tested. The values of A, B and n in the equation σ = A + Bε^n are found. The A value is taken as the stress value corresponding to the 0.2% yield strength of the material, while the B(194.41) and n(0.39) values are obtained from the tensile test data by linear regression analysis.

3.1.3 Ansys Tensile Test Analysis Results

The simulation part of the test was performed using the Explicit Dynamics module. After simulating the tensile test in the Ansys program, the results were obtained and compared with the tensile test results and the results were analyzed. (Figure 6)

According to the tensile test results, the elongation in the length of the material was measured as 6.26 mm. According to the ansys tensile analysis, the elongation was measured as 7.546 mm. The success of the ansys analysis varies depending on the calculated Johnson-cook parameters.

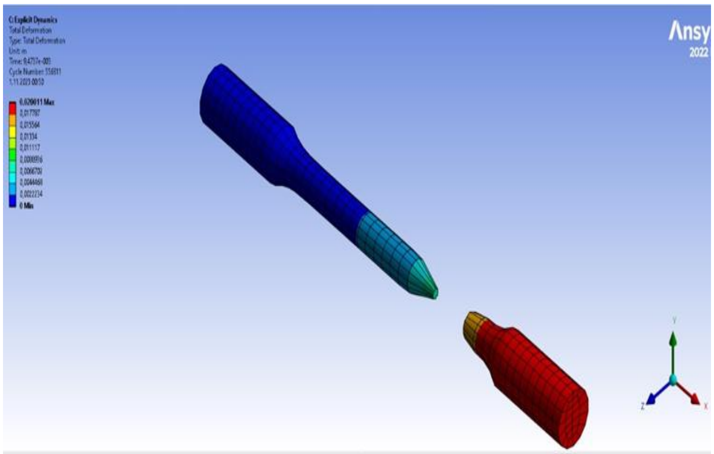

Figure 6. Ansys tensile test

3.2 Fatigue Test Modeling and Analysis in Ansys

In order to simulate the fatigue test in the Ansys program, the material definition and the geometry of the specimen to be tested were created using the Static Structural module. The geometry created for the analysis planned to be performed in the Ansys program must first be meshed and boundary conditions must be determined. The geometry to be analyzed, meshing process and boundary conditions are shown in Figure 7.

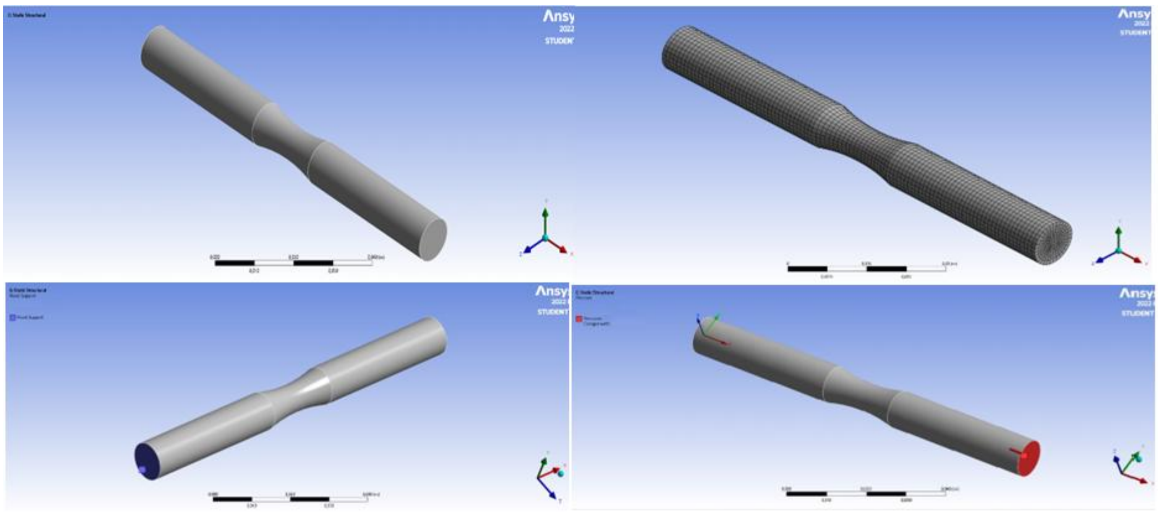

Figure 7. a) cad model b) mesh process c) fixed region d) load region

3.2.1 Ansys Fatigue Test Analysis Results

The results were obtained after the fatigue test simulation was performed in the Ansys program. (Figure 8) Separate analysis was performed for each load applied in the experiments. The results of the analysis and the experimental results were analyzed by drawing the S-N diagram and comparing the results. (Figure 9)

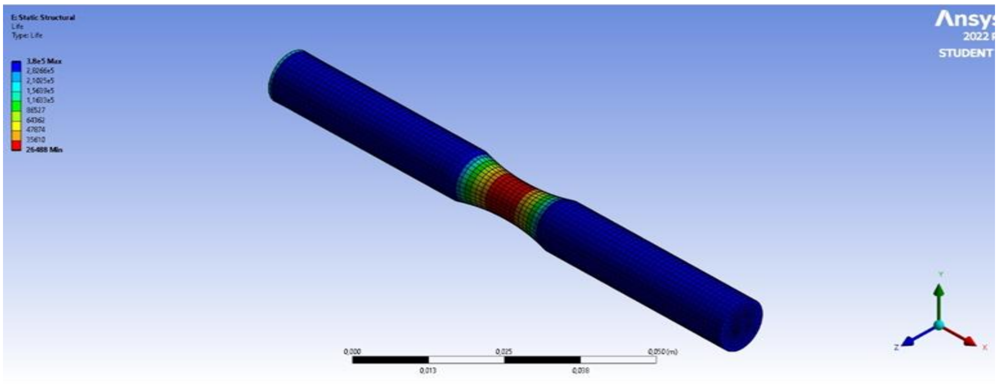

Figure 8.Ansys fatigue test

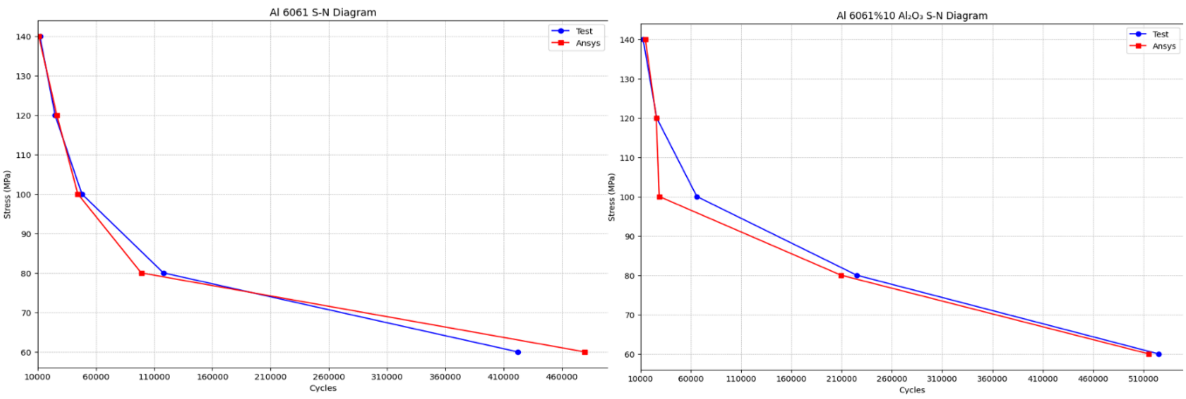

Figure 9.S-N diagrams

4.CONCLUSIONS

In this study, computer-aided tensile and fatigue analysis of Al2O3 particle reinforced aluminum metal matrix composite was performed and compared with experimental results.

Results of computer-aided mechanical analysis:

- As a result of tensile and fatigue tests obtained using Ansys software, values very close to the experimental results were obtained.
- Obtaining results in line with real experiments is crucial to improve design processes and reduce costs.
- The success of the analysis performed in Ansys software depends on a number of important parameters:
    - **Geometry and Modeling:** Correct geometric descriptions and models should be used.
    - **Material Identification:** Material properties must be defined correctly.
    - **Limiting Conditions and Loads:** Must be accurately determined.
    - **Mesh Quality:** An adequate and appropriate mesh should be used.
    - **Analysis Modules:** The right analysis modules must be selected.
- The Johnson-Cook material model for tensile testing is an important tool for mathematically expressing the tensile behavior of the material.
- Accurate and precise specification of Johnson-Cook parameters increases the reliability and accuracy of analysis in engineering simulations.

This study has demonstrated that Ansys software can be used to analyze the computer-aided mechanical behavior of Al2O3 particle reinforced aluminum metal matrix composite and can produce results in agreement with experimental results. The use of the correct parameters increases the reliability and accuracy of the analysis in engineering simulations.

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor Prof. Dr. Metin KÖK, who shared his valuable knowledge with me during this study, took the time when I consulted him, guided me with his patience and showed great interest and support.

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