

T5.5 Case study Problem- Based Learning (PBL)

Title of Case Study / Problem-based learning case

Use of NDT on AM Parts Made out of Composite Powders to Determine the Modulus of Elasticity and Imperfections

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Background:

- **Material:** PA11/12 (Nylon polymer with 11 or 12 Carbons) with various metal/ceramic content
- **Design:** Test coupons should be at least larger than a 2 cm cube
- **Dimensions:** Larger than probe sizes
- **Method:** Selective Laser Sintering (SLS)

Context & Objective:

Additive manufacturing, particularly Selective Laser Sintering (SLS), is widely used to produce geometrically complex polymer components. Polyamide 12 (PA12) is frequently selected as the matrix material due to its low density, high mechanical strength, and excellent sinterability. To further enhance material performance, reinforcements such as ceramic particles and copper (in both spherical and dendritic forms) are introduced into the PA12 matrix.

However, manufacturing parameters, specifically laser energy density, directly impact the internal structure. Insufficient energy density can lead to the formation of internal micro-voids, which negatively affect the material's elastic modulus and overall integrity. The primary goal of this case study is to utilize Non-Destructive Testing (NDT) methods to evaluate how varying reinforcement ratios and energy densities influence the acoustic properties, internal defect formation, and mechanical performance of these composite parts.



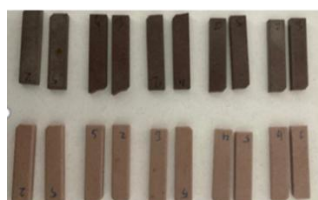
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Illustration of the case study



→ Dendritic Copper and PA12 powder mixture

→ Spherical Copper and PA12 powder mixture

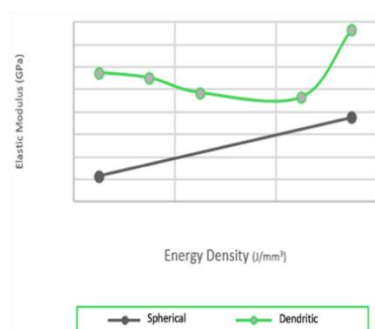
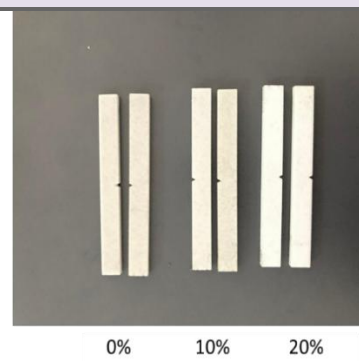


Figure 1. Visual representation of SLS-manufactured PA12 test specimens with varying ceramic and copper (dendritic/spherical) reinforcements, accompanied by a graph illustrating the effect of laser energy density and copper morphology on the elastic modulus.

Additional pictures/information



Figure 2. An example screenshot of a UT device screen during ultrasonic sound velocity measurement



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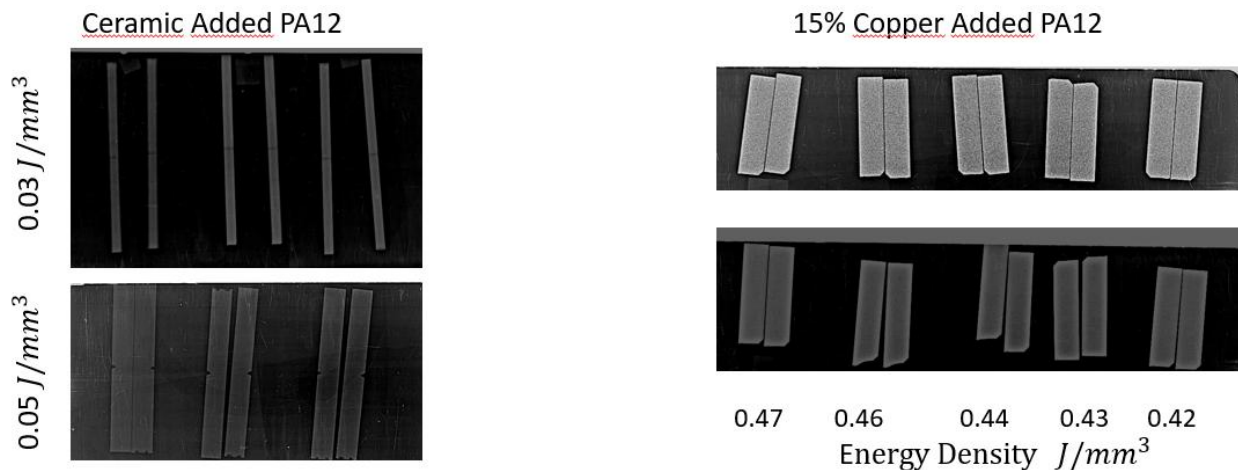


Figure 3. Radiographic images of test samples

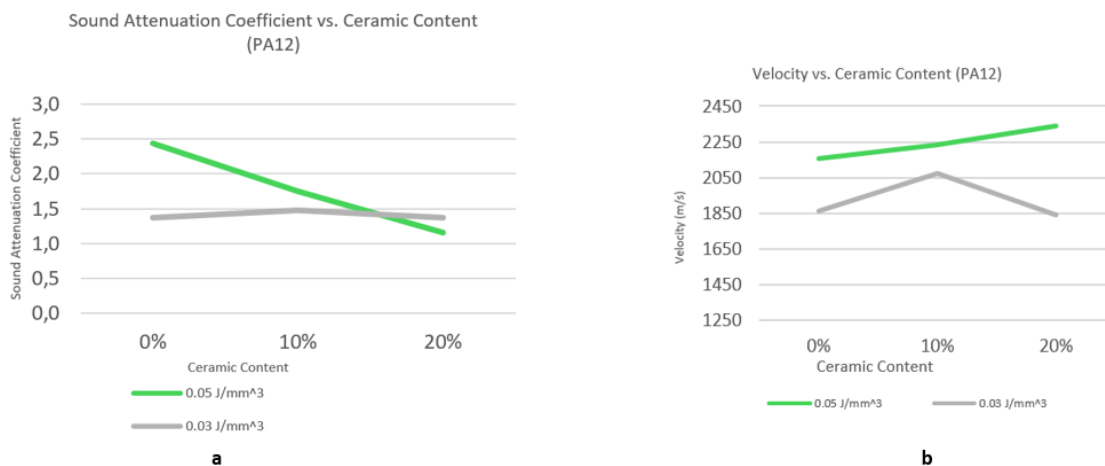


Figure 4. Examples of comparison of ceramic-reinforced PA12 parts: (a) Sound attenuation coefficient and ceramic reinforcement ratio (b) Sound velocity and ceramic reinforcement ratio

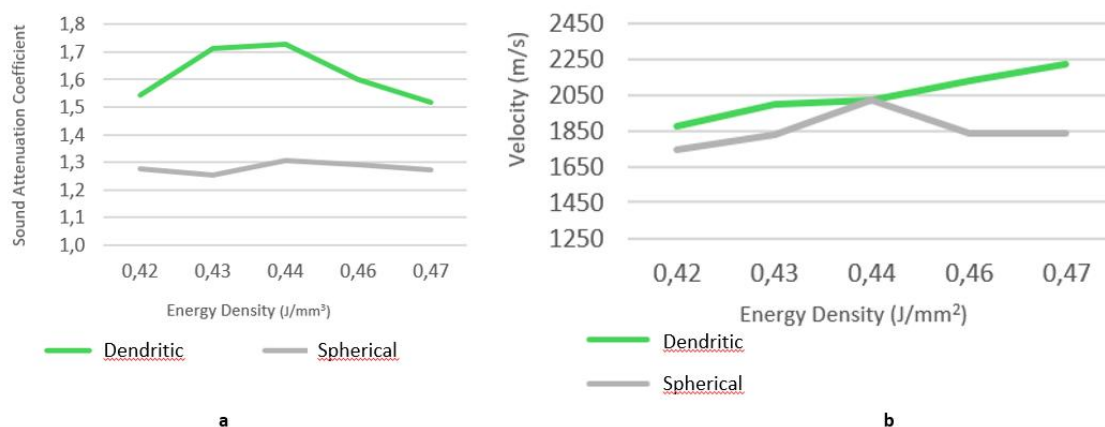


Figure 5. Examples of comparison of copper-doped PA12 parts: (a) Laser energy density and speed of sound ratio (b) Laser energy density and sound attenuation coefficient ratio



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Technical challenge

Goals and Questions:

- Determine the mechanical properties before using the new material mixtures in the final products.
- Compare SLS manufactured samples with the conventionally manufactured samples to check the anisotropic behaviour.
- Balance accuracy and efficiency: choosing between precise, costly results or faster, lower-cost methods
- How do you handle new manufacturing approaches when there are not any standards yet?
- Can you use the same approach on Laser Powder Bed Fusion of metals (Nickel alloys)?

Instructions and Steps to Conduct the Case Study:

- Calibration: Calibrate the UT device using a 5 MHz probe. Apply the coupling agent (oil or honey) to ensure minimum energy loss between the probe and the test coupon.
- Velocity Measurement: Measure the Time of Flight (TOF) to calculate both longitudinal (V_L) and transverse (V_T) sound velocities using the contact or immersion methods.
- Attenuation Analysis: Measure the amplitude of the ultrasonic signal at different depths to calculate the sound attenuation coefficient, which indicates energy loss due to internal structures or defects.
- Radiographic Evaluation: Position the sample between the X-ray source and the detector to visualize volumetric discontinuities (micro-voids caused by insufficient melting).
- Cross-Referencing Data: Compare the calculated elastic modulus from UT with the internal defect mapping from RT to evaluate the overall manufacturing parameters

Detailed solution/ process

To thoroughly evaluate the new material mixtures and assess anisotropic behavior without destroying the samples, a multi-method NDT approach is required.

1. Ultrasonic Testing (UT) - Measuring Modulus of Elasticity & Discontinuities

UT is the primary method used to determine the mechanical properties of the composites. Phased Array is the most effective solution for both contact and immersion methods, providing superior data compared to single or angle probes, which may yield scattered results.

- UT accurately measures both longitudinal and transverse sound velocities to calculate the elastic modulus.

Using the Time of Flight (t_{TOF}) over a known distance (d), longitudinal velocity is found:

$$V_L = \frac{2d}{t_{TOF}}$$

With longitudinal (V_L) and transverse (V_T) velocities, the Poisson's ratio (ν) and Young's Modulus (E) for the material density (ρ) can be calculated.

$$\nu = \frac{1 - 2(V_T/V_L)^2}{2 - 2(V_T/V_L)^2}$$

$$E = \frac{V_L^2 \rho (1 + \nu)(1 - 2\nu)}{1 - \nu}$$



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- **Acoustic Attenuation Reasoning:** Sound attenuation is a critical metric analyzed during this process; higher frequencies result in larger effects on attenuation. An increase in ceramic content typically increases sound velocity but alters (decreases) attenuation. Varying copper morphologies show that spherical copper yields a more homogeneous distribution and a higher elastic modulus compared to dendritic copper. Dendritic copper structures, however, exhibit higher sound attenuation than spherical ones.

2. Radiographic Testing (RT) - Defect Detection

While RT is challenging for planar discontinuities, it is highly effective for detecting volumetric discontinuities.

- **Reasoning:** RT is employed to validate the UT findings visually. X-rays effectively reveal internal pores and voids caused by insufficient melting at lower energy densities (eg, 0.03 J/mm^3 vs 0.05 J/mm^3), explaining the variances observed in the material's density and calculated elastic modulus.

3. Eddy Current Testing

- **Reasoning:** This method is utilized specifically for the copper-reinforced samples to check the amount of conductive materials inside the polymer matrix and to verify overall conductivity.

By cross-referencing the calculated elastic modulus from UT with the internal defect mapping from RT, engineers can reliably qualify these new manufacturing approaches, optimize energy density parameters, and understand the limits of the composite materials before final application.

The Purpose of the elaborated Case Studies

Case studies are structured examinations of real-world situations or challenges designed to bridge theory and practice. They are developed both as a research method and as a learning tool to strengthen analytical and problem-solving skills. By engaging with authentic industrial scenarios, students gain practical insight into complex professional environments.

The purpose of this case studies is to encourage active, learner-centred engagement. They support approaches such as problem-based learning by enabling students to work independently or collaboratively, with or without instructor guidance. Through analysing theoretical concepts within realistic contexts, students learn to interpret data and test results, evaluate alternative courses of action, and develop well-reasoned, creative solutions.

This approach is particularly valuable in sectors such as aerospace, defence, and advanced manufacturing, where challenges are multifaceted and solutions are rarely singular. Because multiple valid solutions often exist, guided facilitation is frequently beneficial to help students structure their reasoning, assess trade-offs, and justify their decisions effectively.



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Competence unit coverage:

	AILEEN competence units	Covered CU
AW_01	Welding: Advanced Metallic Materials in Aerospace and Defence Sectors	
AW_02	Welding: Advanced Welding Processes and Equipment in Aerospace and Defence Sectors	
AW_03	Welding: Advanced Welding Applications in Aerospace and Defence Sectors	
AW_04	Welding: Introduction to brazing technology Knowledge for quality brazed joints	
AW_05	Welding: Fundamentals of Industrial Brazing: Main Processes, Quality Standards & Applications	
AI_01	Inspection: Non-Destructive Testing (NDT) in Additive Manufacturing for metals and polymers	X
AI_02	Inspection: Metrology in Additive Manufacturing for metals and polymers	
AI_03	Inspection: Inspection of AM parts. Material Quality	X
AAM_01	AM: Qualification, Certification and Standards for AM in A&D	X
AAM_02	AM: Quality Assurance & Quality Control for AM in Aerospace & Defence	X
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	
AD_01	Digital: Introduction to Digital Technologies in Advanced Manufacturing	
AD_02	Digital: Data Acquisition and Analysis	
AD_03	Digital: Industrial Internet of Things (IIoT) and Advantages in Advanced	
AD_04	Digital: Artificial Intelligence and Advantages in Advanced	
AD_05	Digital: Automation and Advantages in Advanced Manufacturing	
AD_06	Digital: Potentials of Advanced Simulation and Modelling in Advanced	
AD_07	Digital: Potentials of Digital Twins and Smart Factory Automation in Advanced Manufacturing	
AD_08	Digital: Unlocking the Potential of 3D Models Beyond Technical Drawings in the Aerospace and Defence Sector	
AG_02	Green: Sustainable Design and Environmental Compliance in Aerospace and Defence	

