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# Temporal Changes in the Flexural Properties of 3D-printed ABS Specimens

*This study investigates the environmental aging effects on 3D-printed Acrylonitrile Butadiene Styrene (ABS) produced using Fused Deposition Modeling (FDM) and Digital Light Processing (DLP) techniques. The materials in filament (FDM) and resin (DLP) forms were exposed to UV light, humidity, and temperature fluctuations over two months. Mechanical testing via three-point bending and Fourier Transform Infrared Spectroscopy (FTIR) were employed to assess the impact of these environmental factors. Results showed notable mechanical strength and structural stability differences between the FDM-printed filament and DLP-printed resin ABS under aging conditions. The filament-based ABS exhibited superior mechanical properties, retaining its strength over time, while the resin-based ABS degraded significantly shortly after printing. Despite exposure to ambient environmental conditions, the chemical composition of both materials remained stable throughout the research period.*

***Keywords:*** *Additive manufacturing, ABS, FDM, DLP, three-point bending, aging, FTIR.*

## 1. INTRODUCTION

The use of polymers in 3D printing has revolutionized additive manufacturing, making it possible to produce complex designs and custom structures with high precision. Polymer-based additive manufacturing (AM) has gained widespread popularity because of its many benefits compared to traditional methods, such as injection and blow molding, including reduced production costs, faster prototyping, and improved design flexibility [1,2]. AM enables the production of final products, layer by layer, without the need for traditional setup, fixtures, molds, or tools. It enables digital models, usually created in CAD software, to be directly converted into physical, three-dimensional objects of almost any design or complexity. This approach significantly enhances design freedom by eliminating the limitations imposed by conventional manufacturing methods, allowing the creation of complex geometries and customized parts that would otherwise be impossible or expensive [3- 5].

As the demand for sustainable and innovative manufacturing solutions grows, the development of new polymer formulations continues to evolve, combining additives that enhance mechanical properties, thermal stability, and resistance to environmental factors. The integration of polymers into 3D printing not only drives technological advancements but also lines up with industry trends toward customization, sustainability, and efficiency. One of the key advantages of polymer integration into 3D printing is the considerable reduction in the time it takes to develop and introduce new products to the market [6], which lines up with industry trends toward customization, sustainability, and efficiency.

Among various polymers, Acrylonitrile Butadiene Styrene (ABS) stands out as a popular choice for applications requiring durable and resilient parts due to its properties, including high-temperature resistance, chemical resistance, impact resistance, stiffness, and strength [7]. These properties make ABS particularly suitable for applications requiring durable and resilient parts. However, various factors influence ABS's porosity and overall performance during the printing process. Parameters such as extrusion multiplier, layer thickness, nozzle temperature, raster angle, printing speed, and bed temperature all contribute to the final printed product's mechanical properties and surface finish [8]. ABS is a thermoplastic polymer containing three unequally combined monomeric units, i.e., acrylonitrile, butadiene, and styrene. and its behavior under mechanical stress can vary based on loading modes, molecular weight of the matrix, strain rates, and rubber content [9].

The choice of AM technology influences not only the printing process but also the material's mechanical and structural properties. Fused Deposition Modeling (FDM) utilizes thermoplastic filament polymers that can be melted and extruded, making it one of the most accessible and widely adopted 3D printing technologies [8,10,11]. The adaptability of the FDM process makes it suitable for a wide range of applications, from developing early prototypes to manufacturing fully functional parts while supporting the various types of polymers. Parameters such as dimensional accuracy, surface finish, and mechanical strength are critical to ensure the quality of FDM-printed parts, particularly in applications where these factors impact functionality

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and durability [12-14]. It is also important to consider the choice of 3D printers, as professional printers, unlike consumer-grade ones, typically require longer production times and incur higher costs [15]. However, achieving optimal results requires a detailed understanding of how different printing parameters affect the final output.

Vat photopolymerization (VP) technologies, such as Digital Light Processing (DLP), use LED projectors of ultraviolet (UV) light to cure liquid photopolymers layer by layer. Photoinitiators within the resin initiate a polymerization reaction upon UV exposure by the formation of molecular chains and the subsequent development of a solid layer [16]. Compared to FDM, DLP printing provides finer detail and smoother surface finishes but requires specific resin formulations and post-processing to achieve optimal mechanical properties.

Given ABS's unique chemical structure and properties, understanding how it performs mechanically under stress is crucial for its use in real-world applications. The mechanical behavior of 3D-printed parts, particularly under flexural stress, can vary significantly depending on factors such as layer height, printing orientation, raster angle, and infill patterns [14]. In additive manufacturing, three-point bending tests are commonly used to evaluate a material's strength, flexibility, and resilience to applied forces. This method is widely recognized as an effective means of assessing the structural integrity of 3D-printed components, offering valuable insights into aspects such as stiffness, load-bearing capacity, and resistance to deformation. These tests are especially relevant for polymers like ABS, as they help reveal the material's durability and performance under bending loads, which is essential for predicting the lifespan and reliability of parts in practical applications [17]. Flexural measurements have shown that ABS can accumulate a larger amount of energy before fracture, which affects the ultimate strain [18].

The reliability of ABS 3D printed specimens, their durability, and long-term performance are influenced not only by their mechanical behavior but also by their ability to withstand environmental challenges over time. Understanding the effects of different aging conditions on 3D-printed parts is essential for predicting the lifespan and reliability of components in various applications. Studies have shown that physical and chemical changes in ABS blends, such as those induced by heat or prolonged exposure to natural and artificial aging are closely tied to factors like time and temperature [19]. For example, a 24-day aging evaluation of Accura resin used in stereolithography in controlled and uncontrolled environments indicated similar behavioral trends between groups [20]. Likewise, the mechanical properties of methacrylate stereolithographic resins have been found to correlate strongly with UV post-curing conditions and thermal history, revealing how these factors influence material strength and stability over time [21]. However, despite these findings, there is currently a lack of comprehensive studies specifically on ABS resins, limiting direct comparisons and leaving opportunities for further research on the aging behaviors of this material.

Furthermore, Fourier-transform infrared (FTIR) spectroscopy is a valuable technique for evaluating the chemical integrity of materials by analyzing molecular composition. FTIR helps in understanding degradation mechanisms by identifying changes in characteristic functional group vibrations, thus offering insights into the material's long-term performance. Different researchers used FTIR analysis to study the structural changes in ABS during the 3D printing process. For example, Poyraz et al. observed that ABS-like resin samples displayed characteristic peaks associated with ABS compounds and noted significant spectral changes related to degradation in raw, as-built, and post-cured material forms [17].

The study by Pop et al. highlighted how these structural changes could affect the mechanical properties of ABS, such as its flexibility and strength, making FTIR a valuable tool for understanding the material's behavior during and after the printing process [22]. San Andrés et al. used FTIR spectroscopy to examine the composition and long-term behavior of ABS materials in fine art applications under environmental conditions such as light exposure and humidity. FTIR spectra showed signs of degradation in the ABS material [23].

This study investigates the mechanical and chemical behavior of specimens fabricated through FDM from filament-based ABS and DLP-LCD from resin-based ABS. Specimens were subjected to three-point bending tests to evaluate flexural strength and stiffness, while FTIR spectroscopy was employed to examine chemical integrity and potential degradation following mechanical testing and aging over two months.

## 2. METHODOLOGY

### 2.1 Specimen – Material and Preparation

In this research, two commercially available materials were used: ABS filament from Creality (Shenzhen, China) and ABS-like resin from eSUN (Shenzhen, China). The geometry of the specimens was designed using CAD software (SolidWorks 2020 from Dassault Systèmes SE, Vélizy-Villacoublay, France), respecting the ISO 178:2019 standard for flexure testing (Figure 1).

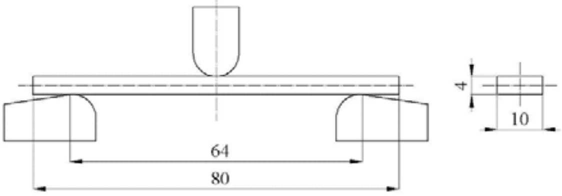

**Figure 1. The geometry of the specimen for three-point bending testing, according to the standard.**

When the specimen design was complete, it was further converted into an STL file format. This file was then sliced using Simplify3D (Cincinnati, OH, USA) for FDM and ChiTuBox (Shenzhen, China) for DLP-LCD.

Printing FDM parameters included a nozzle temperature of 250°C, a build platform temperature of 90°C, and a layer height of 0.24 mm. DLP-LCD process fabricated specimens using a 405 nm LCD projector and 0.005 mm layer thickness. Additionally, the specimens were post-cured under UV light to finalize the material's structure.

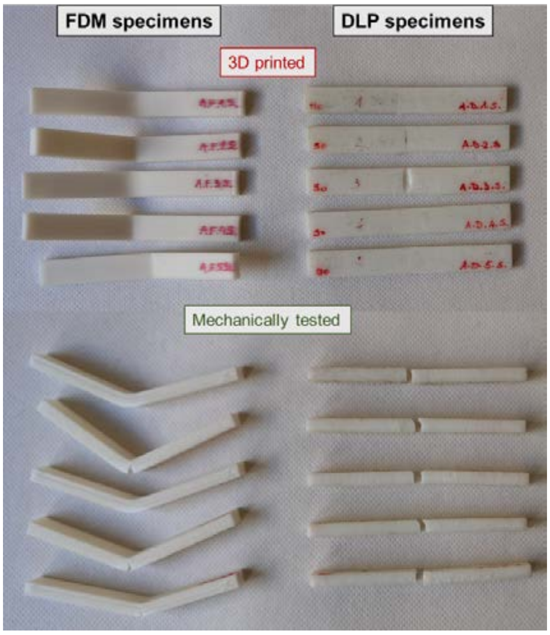

**Figure 2. 3D printed and mechanically tested specimens.**

A total of 30 specimens were prepared for this study. Of these, 15 were fabricated using ABS filament on the Creality CR-10 Smart Pro FDM printer (Shenzhen, China), and 15 were produced using ABS-like resin on the Creality LD-002R DLP printer (Shenzhen, China). For each group of 15 specimens, five were tested immediately, five after one month, and five after two months of aging. All specimens were printed with a 90° orientation and a 100% infill density (Figure 2).

## 2.2 Experimental setting

### Mechanical testing

The mechanical testing of all 30 specimens was conducted using the Shimadzu AGS-X universal testing machine (Shimadzu Corp., Kyoto, Japan), which was equipped with a 100 kN load cell (Figure 3). The testing speed was set to 1 mm/min in compliance with the ISO 527-2 standard.

**Figure 3. Three-point bending testing of the specimen.**

The raw data, comprising force and displacement measurements collected by sensors during testing, were processed using the TRAPEZIUM soft–ware. Subsequently, average engineering stress-strain curves were generated and analyzed with Matlab R2022b software (MathWorks, Natick, MA, USA). From these curves, key mechanical parameters were determined, including flexural modulus, flexural stren–gth, and flexural strain at break.

### Aging

The specimens were placed in a natural environment and cleaned daily over a two-month period. The aging process chosen for this research wasn't based on any standard or previous studies. The aim was to mimic everyday indoor conditions and to observe how the materials would behave over time in a resting state. During the aging period, the specimens were kept in an open plastic box, shielded from direct sunlight. However, they did receive natural daylight, as well as artificial light at night. The temperature in the environment varied between 17 to 25°C, as it corresponds to seasonal changes during the study period. For hygiene, the specimens were washed in water heated to 37°C using Frosch gel.

### FTIR

To study chemical changes caused by aging, an FTIR analysis was performed using the Thermo Scientific Nicolet Summit spectrometer, equipped with an ATR accessory and a diamond crystal (Smart Orbit, Thermo Scientific, Madison, WI, USA). The focus was on identifying shifts in vibrational modes of functional groups, particularly in the butadiene and acrylonitrile components of ABS. Spectra were recorded in the mid-IR range (4000–400 $cm^{-1}$), with 32 scans at a resolution of 4 $cm^{-1}$. Background spectra were collected under the same conditions. Data processing, including smoothing, baseline correction, and automatic ATR adjustment, was carried out using OMNIC software (version 7.0, Thermo Scientific, USA).

## 3. RESULTS AND DISCUSSION

## 3.1 Flexural testing

Three-point bending test was performed on thirty specimens, among which fifteen were printed by FDM technology and fifteen by DLP-LCD technology. Further, each group of fifteen specimens contains three aging groups of five specimens: 0m group- immediately after the printing, 1m group- after one month of aging, and 2m group -after two months of aging. Each group endured mechanical testing under the same conditions, and then the raw data from the testing machine were processed using Matlab software and presented in Figures 1 and 2.

The stress-strain curve for the aging group is the average curve for five values in the same testing session created for the interval where all five specimens had available data. Therefore, the interval after the first specimen failure and onward was not included. FDM specimens are presented in Figure 1, and DLP-LCD specimens are presented in Figure 2, pointing out the potential change in the flexural behavior caused by aging.

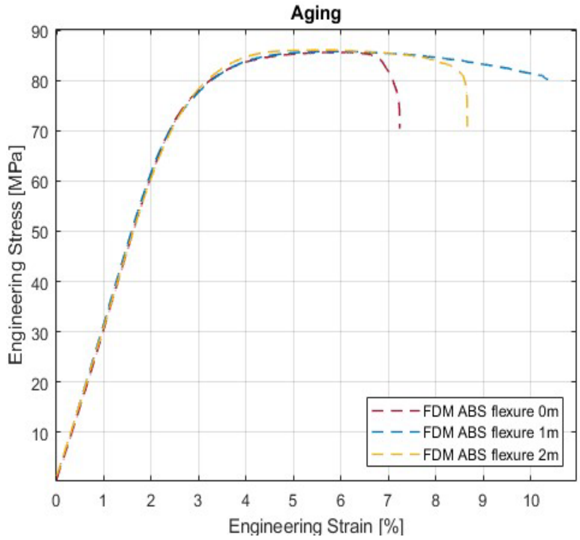

**Figure 4. Stress-strain curves for aging specimens made by FDM technology.**

The average curves for the FDM specimens (Figure 4) reveal overlying for all curves until the engineering strain is reached. Afterward, the flexural behavior is similar, although specimens exhibit more durability during aging. The flexural strength of the ABS filament has adjacent values for the 0m and 2m groups.

Opposing FDM, the average curves for the DLP-LCD specimens (Figure 5) expose quite different material behavior during aging, whereas the curves have different slopes in elastic regions. The aging decrease of the flexural modulus and the material's flexural strength are significant. Specimens in the 1m group show unexpected behavior and increased durability during aging. The same situation occurs for one-month mature FDM and DLP-LCD specimens. Upgraded mechanical properties, especially durability, ought to be regarded as impermanent. Results for the 2m group indicate that.

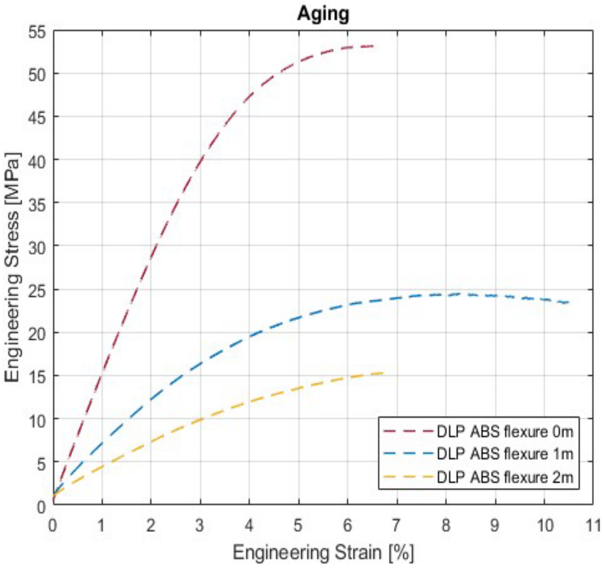

**Figure 5. Stress-strain curves for aging specimens made by DLP-LCD technology.**

In this paper, we compare three flexural parameters: flexural modulus, flexural strength, and flexural strain at failure. The average values of these parameters are presented in Figures 6 to 8.

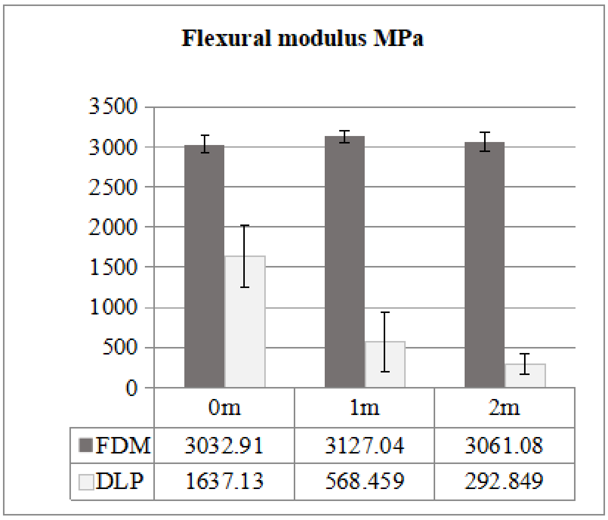

**Figure 6. Flexural Modulus for aging specimens made by FDM and DLP-LCD technology.**

For FDM specimens, aging and bathing for two months led to fluctuations in the following properties:

1. Flexural modulus increases by less than 1%,
2. The flexural strength of the material increases up to 0.5%,
3. Flexural strain at failure of the material increases up to 46%.

For DLP-LCD specimens, aging and bathing for two months led to fluctuations in the following properties:

1. Flexural modulus decreases up to 82%,
2. The flexural strength of the material decreases up to 76%,
3. Flexural strain at failure of the material increases up to 45%.

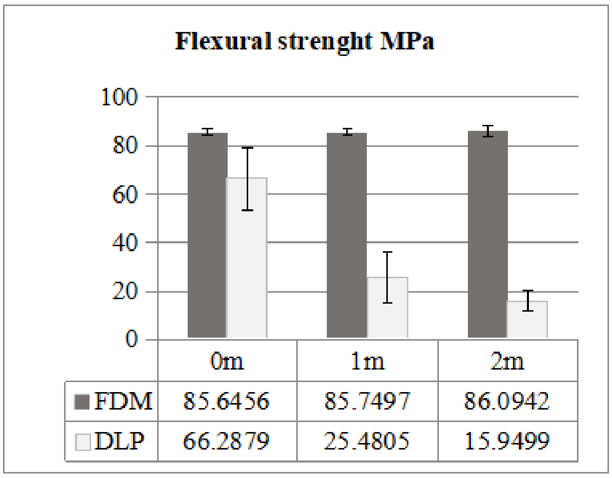

**Figure 7. Flexural strength for aging specimens made by FDM and DLP-LCD technology.**

Three-point bending tests play a key role in assessing the mechanical properties and structural strength of materials, especially polymers and composites. These tests help in choosing appropriate materials, guiding design decisions, and improving safety by evaluating how materials behave under stress [9]. Together with inclusion of aging mechanisms, they can be used to study how environmental factors like humidity, temperature, and UV exposure affect material properties, which is important for polymers that tend to degrade in varying conditions.

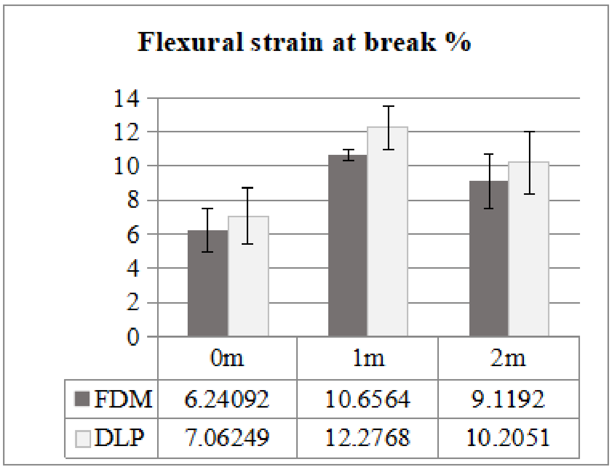

**Figure 8. Flexural strain at break for aging specimens made by FDM and DLP-LCD technology.**

### 3.2 FTIR

The influence of the aging process on the physical properties of ABS filament and ABS-like resin was monitored with FTIR spectroscopy. FTIR spectra comparison of three aged groups (i.e., immediately after specimen printing and after 1 and 2 months of aging) for FDM specimens is presented in Figure 9, and for DLP specimens is presented in Figure 10.

According to the presented results, in FTIR spectra of ABS filament material, the stretching vibrations of aromatic and aliphatic C–H were present in the range of 3200–3000 cm$^{-1}$ and 3000– 2800 cm$^{-1}$, respectively. Characteristic acrylonitrile unit (C≡N) absorption appears at 2237 cm$^{-1}$. The transmission at 1638 cm$^{-1}$ and 1494 cm-1 represents the stretching vibration of the C=C double bond from butadiene units and the stretching vibration of the aromatic ring from the styrene units, respectively. The strips from the deformation of hydrogen atoms bound connection to alkene carbons are present at 967 cm$^{-1}$ and 911 cm$^{-1}$ for 1,4 butadiene and 1,2 butadiene units, respectively. The deformation vibration from aliphatic and aromatic C-H bonds is represented with intense strips at 759 and 698 cm$^{-1}$ and C=C aromatic at 541 cm$^{-1}$. Results are in accordance with FTIR analysis in [23,24].

Regarding the FTIR results for aging ABS-like resin, after normalization on CH vibrations on 2935 cm$^{-1}$, a trend of increasing intensity of N-H stretching bands at 3342 cm$^{-1}$ and decreasing bands in the fingerprint region such us amide I at 1730–1700 cm$^{-1}$ were detected. Observed C=C skeletal stretching at 1640 cm$^{-1}$ from the benzene ring and another large peak at 1529 cm$^{-1}$, showing in-plane NH deformation with CO and CN stretching (Amide II). Another prominent peak at 1072 cm$^{-1}$ due to C–O–C stretching was present. According to the presented results in Golubović et al., the FTIR spectra are very similar to the PLA-like resin material, known as polyurethane acrylate UV curing resin [25].

Recent studies using FTIR analysis have highlighted the degradation patterns in PLA and ABS, with changes in the absorption spectra indicating material breakdown. In PLA, these changes occur in functional groups related to ester bonds, while in ABS, degradation is observed in its aromatic structures, shedding light on how different environmental conditions impact the stability and reliability of different polymers over time [21].

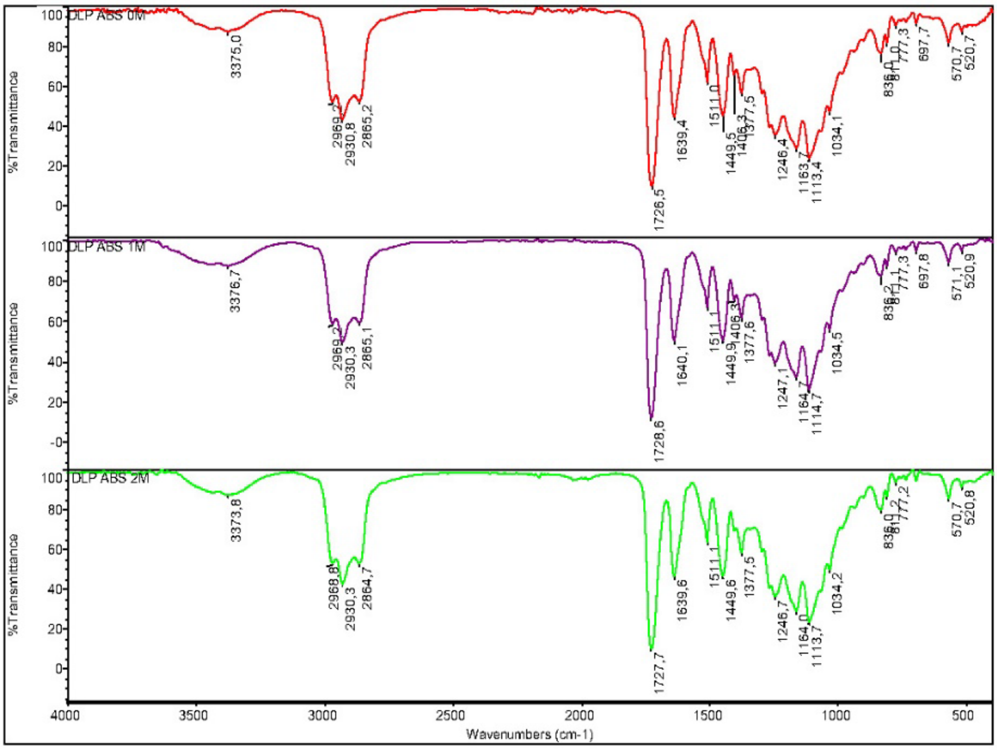

**Figure 9. FTIR analysis of aging specimens made by FDM technology.**

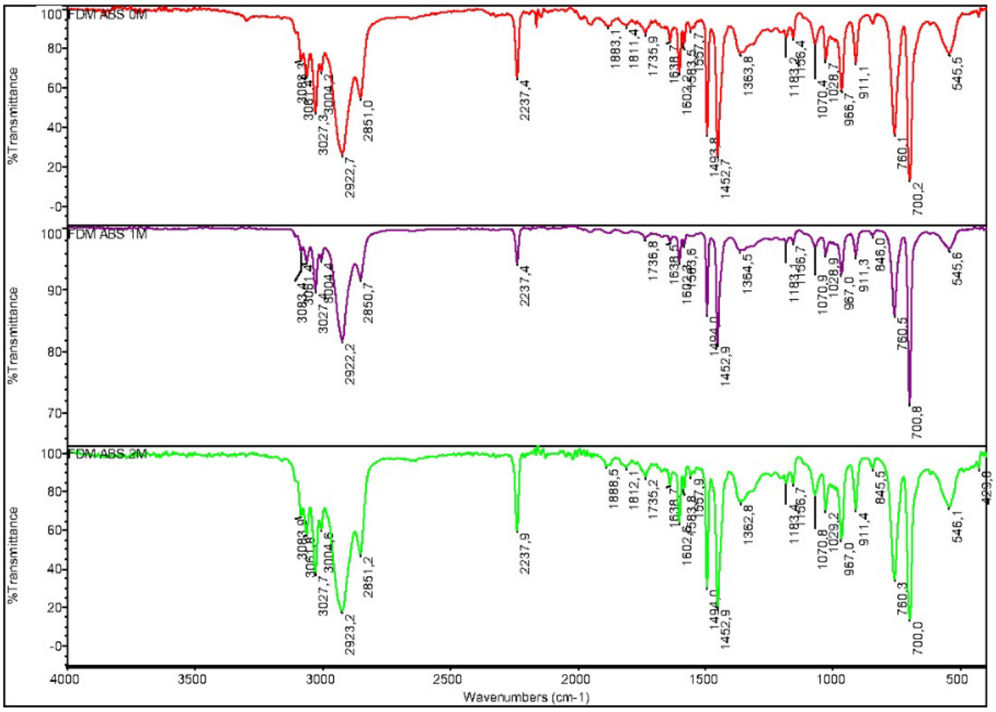

**Figure 10. FTIR analysis of aging specimens made by DLP technology.**

## 4. CONCLUSIONS

The integration of polymers into additive manufacturing (AM) is not only driving technological progress but also aligning with industry trends toward greater customization, sustainability, and efficiency. A thorough understanding of the properties and behavior of ABS is essential for advancing AM technologies, as it impacts material performance, adaptability, innovation, quality standards, and future research directions.

This research underscores the scientific importance of understanding the mechanical and chemical behavior of 3D-printed ABS filament and ABS-like resin, materials with similar origins but distinct chemical compositions and processing characteristics. Three-point bending tests proved particularly effective in evaluating the long-term durability and mechanical performance of 3D-printed ABS parts. It was demonstrated that FDM-printed ABS filament exhibits stable flexural strength and modulus over two months, making it a good choice for applications requiring long-term durability and stability. In contrast, DLP-LCD-printed ABS-like resin, while offering initial flexibility, showed deterioration in characteristics under ambient light exposure, highlighting its limitations for prolonged use.

Complementary FTIR analysis confirmed the chemical stability of ABS filament over time, while ABS-like resin exhibited notable aging-related changes in its chemical structure. By offering a comparative evaluation of two different 3D printing processes using ABS-like-wise materials, this research provides insights into the tailored selection of materials and methods, enabling users to choose between FDM and DLP-LCD technologies based on specific mechanical and other demands. This dual approach supports the optimization of additive manufacturing processes for diverse applications. Results shown here guide material selection in custom manufacturing, prototyping, and end-use products, supporting the development of more reliable and sustainable solutions.

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### *Acronyms*

| | |
|---|---|
| ABS | Acrylonitrile Butadiene Styrene |
| FDM | Fused Deposition Modeling |
| DLP | Digital Light Processing |
| LCD | Liquid Crystal Display |
| FTIR | Fourier-Transform Infrared Spectroscopy |

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## ВРЕМЕНСКЕ ПРОМЕНЕ У САВОЈНИМ СВОЈСТВИМА 3Д ШТАМПАНИХ АБС УЗОРАКА

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Приказано истраживање указује на ефекте старења материјала акрилонитрил бутадиен стирена (АБС) под утицајем фактора околине, који су израђени коришћењем техника Моделовање фузионим депоновањем материјала (ФДМ) и дигитално процесуирање светлошћу (ДЛП). Материјали, у форми филамента (ФДМ) и смоле (ДЛП), били су изложени УВ светлу, влажности и температурним флуктуацијама током периода од два месеца. Како би се проценио утицај ових фактора, коришћени су механички тестови савијања у три тачке и Фуријеова инфрацрвена спекторскопија (ФТИР). Резултати су показали значајне разлике у механичкој чврстоћи и структуралној стабилности између ФДМ-штампаног филамента и ДЛП-штампане смоле под условима старења. Филамент базиран на АБС-у показао је боље механичке особине, задржавајући своју чврстоћу током времена, док је смола на бази АБС-а значајно деградирала убрзо након штампања. Упркос изложености амбијенталним условима, хемијски састав оба материјала остао је стабилан током трајања истраживања.