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RESEARCH ARTICLE

Investigation of the compression behavior of ABS/EVA polymer blends

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Abstract

Thermoplastics offer superior mechanical properties, recyclability, lightweight, and manufacturability that make them attractive replacements for metals in various engineering applications. Polymer blending is a popular technique for improving polymer matrix properties. It eliminates the need for new polymer synthesis and is a simple and rapid process. In this study, the effect of blend composition and strain rate on the compression behavior of ABS/EVA polymer blends is investigated. Blends containing 10% to 30% EVA were melt-mixed using a twin-screw extruder and then used to produce compression test specimens using Fused Filament Fabrication (FFF). Fourier Transform Infrared (FTIR) spectrometry studies have been used for the chemical characterization of the blends and have provided insight into the chemical properties of the blends. Uniaxial compression tests were also performed to investigate the effect of EVA composition and strain rate on the compression behavior of ABS/EVA blends. The relationships between EVA blend composition and compression behavior at varying strain rates were detailed and disclosed.

1. Introduction

Additive manufacturing (AM) has been used in the automobile and aerospace industries since the early 1980s [1]. In fields such as military applications, automotive, aerospace, and medical devices, it is crucial to comprehend the mechanical properties of polymers across various strain rates, temperatures, and pressures. These properties are not only dependent on the composition and microstructure of the materials but also on external factors such as pressure, temperature, and strain rate [2]. Investigating the mechanical properties of materials used for 3D printed structures is crucial as mechanical performance is a significant factor for structural parts [3]. Fused Filament Fabrication (FFF) or Fused Deposition Modeling (FDM) is gaining attention as an attractive 3D printing technique due to its fast processing time and low cost [4]. It is important to note that the widespread use of FDM technology, one of the innovations of additive manufacturing, is closely tied to the development of polymers that can meet the necessary mechanical and material properties for rapid production. However, the development of polymer materials has led to the exploration of new polymer blends obtained by combining multiple polymers instead of relying on a single polymer. This approach has gained significant attention.

Blends of polymers have received a great deal of attention in modern research [5]. Two or more polymers or copolymers are combined to form polymer blends [6]. To develop products with improved mechanical properties using affordable polymer materials, polymer blending is a common practice [7]. Blending has advantages over synthesizing a new material, including ease of processing and cost reduction by skipping the tedious polymerization process. It is important to note that this statement is objective and does not include any subjective evaluations. A blend offers the combined properties of carefully selected partner materials. Polymer blends are utilized in a variety of applications due to their ability to achieve desirable properties that are not attainable with a single polymer. These properties include improved toughness, better modulus and stiffness, superior thermal stability, flame retardant properties, and barrier properties [8]. Examples of commonly used matrix materials for polymer blends are nylon, polyester, epoxy, polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polylactide acid (PLA), and polyamide (PA) [9,10]. Of these, ABS and PLA are the most widely used thermoplastic materials. [11–14]. Acrylonitrile butadiene styrene (ABS) is one of the most common FDM materials with good print quality and mechanical properties [12,15,16]. ABS has unique properties, including excellent mechanical response, chemical resistance, fine surface finish, and good processing properties [17]. ABS is frequently used in various consumer products, communication equipment, automotive parts, and household appliances that require impact resistance, dimensional stability, and electrical insulation [18,19]. ABS is widely accepted in automotive and electronic industries because it can blend with various thermoplastics and elastomers [20].

However, in studies conducted on the use of ABS, blends are obtained using fiber materials and polymers to improve their properties with different additives when the polymer alone is insufficient [21]. The development of the properties of new polymer materials obtained with these mixtures and their better working conditions come to the fore. Elastomer-thermoplastic blends are commonly used in various industries due to their shared properties of thermoplastics and rubber [8]. In blends made with different polymers, excellent toughening agents such as EVA [22], TPU [23], [24], SAN [25], and TPE [12] are used as additives to increase the strength and durability of the material [22].

EVA copolymer is a thermoplastic elastomer with both stiffness and flexibility. Various industrial applications in the

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footwear industry utilize it, including soles, insoles, melt adhesives, bottle caps, and cable sheathing [26]. In situations where ABS is not suitable, the preferred alternative can be ABS/EVA blend products. EVA can be a valuable addition to the blend as it offers many benefits. EVA is a non-toxic material, which makes it safe for use in consumer products like shoes, toys, and even food packaging. It is gaining popularity in various industries because it is easy to process and recycle, making it eco-friendlier than other plastics.

In the studies of ABS/EVA polymer blends; mechanical properties such as tensile, flexural, and impact strength were analyzed to determine the most suitable EVA percentage for the MA-g-ABS matrix produced by injection molding [22]. They found that the impact strength of samples with 6% EVA additive by weight increased by 132%, and although there was a slight decrease in flexural strength in general with the additives, the tensile strength was higher than pure ABS. Gul et al. [27], added 1-7% Na-Montmorillonite (OMMT) clay to the most suitable ABS/EVA mixture and produced it by injection molding. As a result, they found a significant increase in tensile strength and tensile modulus without rupture. When examining studies on different polymer blends and composites, similar results are obtained. The mechanical properties of PLA/PBAT polymer blends in static and dynamic compression are evaluated by Yamamura et al [28]. The blended PLA exhibits lower Young's modulus and yield stress compared to neat PLA. In another study, the effect of HA addition to PLA and PCL matrix was investigated. Mechanical characterization was conducted through a uniaxial compression test. While it is true that the compressive strength tends to decrease as the PCL content increases, it is worth noting that the 90PLA10PCL blend yielded even lower compressive strength results than the other blends [1].

While some studies on ABS/EVA and other blends are in the literature review, limited has been conducted on additive manufacturing (AM). Despite the limited studies on the injection molding method, considering the lack of literature on this subject, this study, ABS/EVA blends were produced in different composition ratios using FFF, an additive manufacturing method. For this purpose, filaments containing 10-20-30% EVA with ABS were produced using a 3D printer for experimental studies. The effect of EVA additive on the chemical and mechanical properties of blend samples produced using additive manufacturing method was investigated. To determine the chemical and mechanical behaviors of ABS and their blends, FTIR analyzes and uniaxial compression tests were carried out.

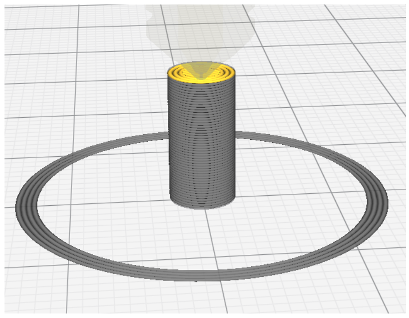
2. Materials and methods

2.1. Materials

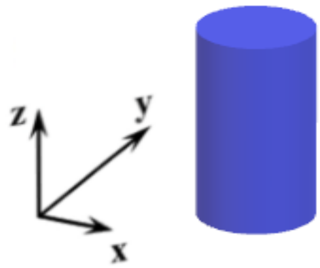
ABS is a copolymer made up of Acrylonitrile, Butadiene, and Styrene. For this research, we utilized the LG brand HI121H material that is available in the market. It has a density of 1.05 gr/cm3, Melt flow index (MFI) of 22 g/10 min, and a Notched izod impact value of 270 Jm. The copolymer EVA is made up of a combination of ethylene and vinyl acetate. For this research, we utilized EVA 2518CO material from the Sipchem brand. This copolymer comprises 18% vinyl acetate and has a MFI value of 2.5 g/10 min, a density of 0.935 g/cm3, as well as an elongation value of 260% up to yield and over 800% up to fracture.

ABS and EVA were dried at 80°C for 3 hours to prevent moisture degradation during extrusion [23]. Blends of ABS and EVA were created using a twin screw extruder with 16 mm diameter shafts. Blend granules were produced using a professional filament production extruder in FILAMEON, with a diameter tolerance of 0.02 mm, after the melt mixing process.

The compression specimens were made the standard of ASTM D695 and 5x10 mm (diameter/length) dimensions. The CAD software was used to design a three-dimensional model of the test sample, which was then sliced by Creality Slicer 4.8.2. The resulting slices were uploaded to the 3D printer using an SD card. The samples were printed using additive manufacturing on a Creality CR200-B 3D printer, with a nozzle diameter of 0.4 mm. The parameters used in the FFF printer are listed in Table 1. 3D model, the printing plane (XY) and schematic of compression test are seen in Figure 1a-c.



(a)



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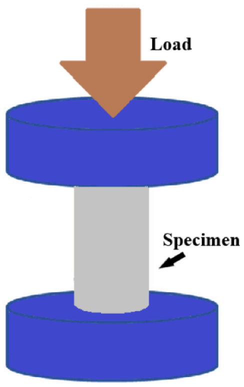


(c)

Figure 1. (a) 3D model of specimen, (b) printing plane (c) schematic of compression test

Table 1. FFF process parameters

Infill pattern	Lines
Infill density, %	100
Print temperature, °C	230
Build platform temperature, °C	100
Print speed, mm/s	40
Filament diameter, mm	1.75
Nozzle diameter, mm	0.4
Layer height, mm	0.2

2.2. Chemical Characterization and Compression Tests

Chemical characterization and mechanical behavior of neat ABS and ABS/EVA blends were examined with Fourier Transform Infrared (FTIR) spectroscopy and compression tests, respectively. FTIR analysis was completed on the Perkin Elmer 100 series spectrometer to determine the chemical formation of ABS and ABS/EVA blends. FTIR spectra were recorded in the 4000-400 cm^{-1} range with 2 cm^{-1} resolutions. From this analysis, the peaks and shifting on the spectrum were obtained and examined for chemical structures.

Compression tests were carried out for the mechanical behavior of neat ABS and ABS/EVA polymer blends. In these tests, the mechanical behavior of specimens is revealed from compression tests using the Universal Tensile/Compression Test Machine. Compression tests were conducted at room temperature and strain rates from 0.001 to 0.1 s^{-1}. It is aimed to examine the compression behavior of neat ABS and ABS/EVA blend materials depending on the strain rate through compression tests at different strain rates. Compression tests were performed with at least three compression test specimens to obtain repeatability of the tests. Also, the presented curves and properties were calculated as the average of each neat ABS and ABS/EVA blend. From compression tests, the effect of blend composition and strain rate on yield stress of specimen were examined.

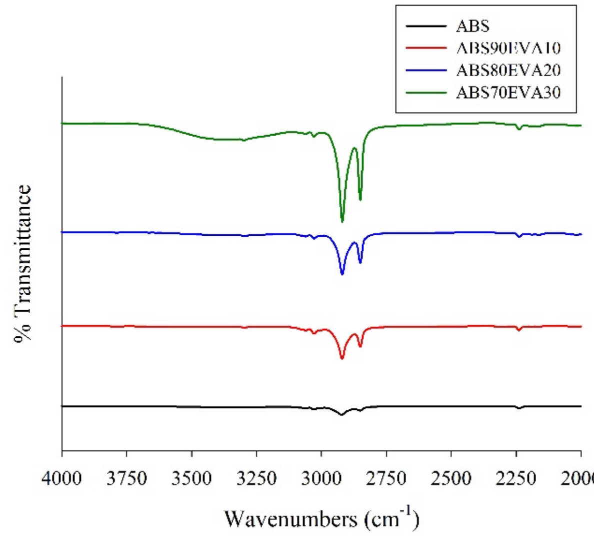
3. Results and discussion

3.1. Chemical Characteristics

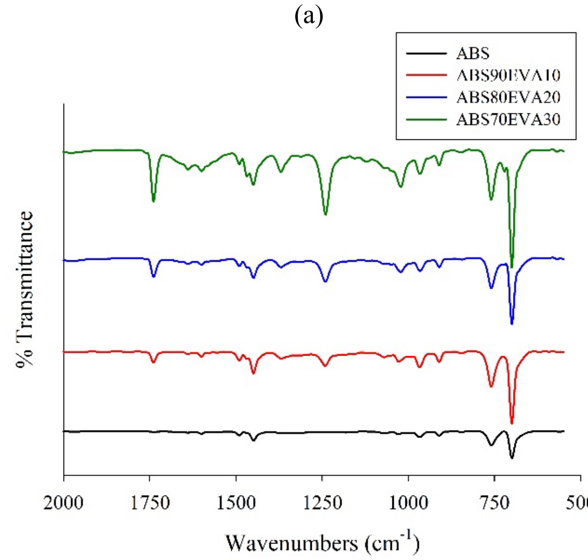
The FTIR spectrum of neat ABS and ABS/EVA blends are given in Figure 2a-b for each blend composition ratios. IR spectra are normalized in order to examine the peak intensities of the wavenumber and the changes in the characteristic peaks of ABS and EVA materials. The characteristic ABS peaks are the absorption peaks at 697 cm^{-1}, 735 cm^{-1}, 966 cm^{-1}, 2240 cm^{-1}, 2850 cm^{-1} and 2922 cm^{-1} wave numbers [28]. Among the characteristic peaks seen in the neat ABS structure, the 2240 cm^{-1} absorption peak is the C≡N stretching peak and is associated with its thermal stability. In addition to the characteristic ABS peaks, characteristic peaks at wavenumbers 1025 cm-1, 1234 cm^{-1}, 1371 cm-1, 1466 cm^{-1}, 1742 cm^{-1}, 2850 cm^{-1} and 2916 cm^{-1} from EVA material in ABS/EVA blends are observed in IR spectra [29]. It was observed that the characteristic EVA peak intensities increased with the increase in the EVA composition ratio in the structure. In addition, it was determined that ABS/EVA blends showed characteristic peaks from both ABS and EVA and no shift was observed in the peaks obtained in the IR spectrum. The observation of characteristic peaks from EVA and ABS materials without peak shift in ABS/EVA blends is considered as an important intrinsic compatibility indicator.

3.2. Compression Behavior

The mechanical behaviors of ABS and ABS/EVA blends were obtained from experimental compression tests. The compression stress-strain curves of neat ABS and ABS/EVA blends are given in Figure 3. From Figure 3, the influence of EVA additives on the compression response of ABS/EVA blends was investigated. With increase in the EVA content in ABS/EVA blend structure, yield strength, ultimate compression strength and elastic modulus decrease compared to neat ABS. However, the ABS80EVA20 sample has superior yield and elastic modulus compared to samples with ABS90EVA10 and ABS70EVA30. The curves for all blends were lower than those for neat ABS. In ABS/EVA blends, compressive strength decreased with increasing EVA content, as was the trend mentioned in another study [1,30]. The EVA copolymer used in the blend has a rubber effect and toughening mechanism in the structure, which may cause this situation to develop [21].



(a)



(b)

Figure 2. FTIR spectrum of neat ABS and ABS/EVA blends in the range of (a) 4000 cm^{-1}-2000 cm^{-1} and (b) 2000 cm^{-1}-500 cm^{-1}

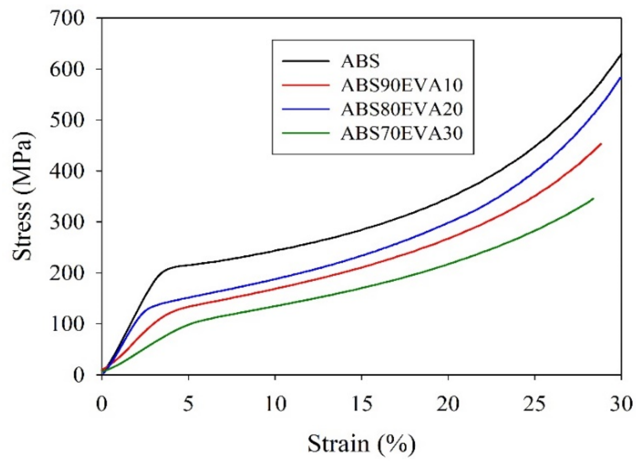


Figure 3. Typical compressive curves of the ABS and ABS/EVA blends

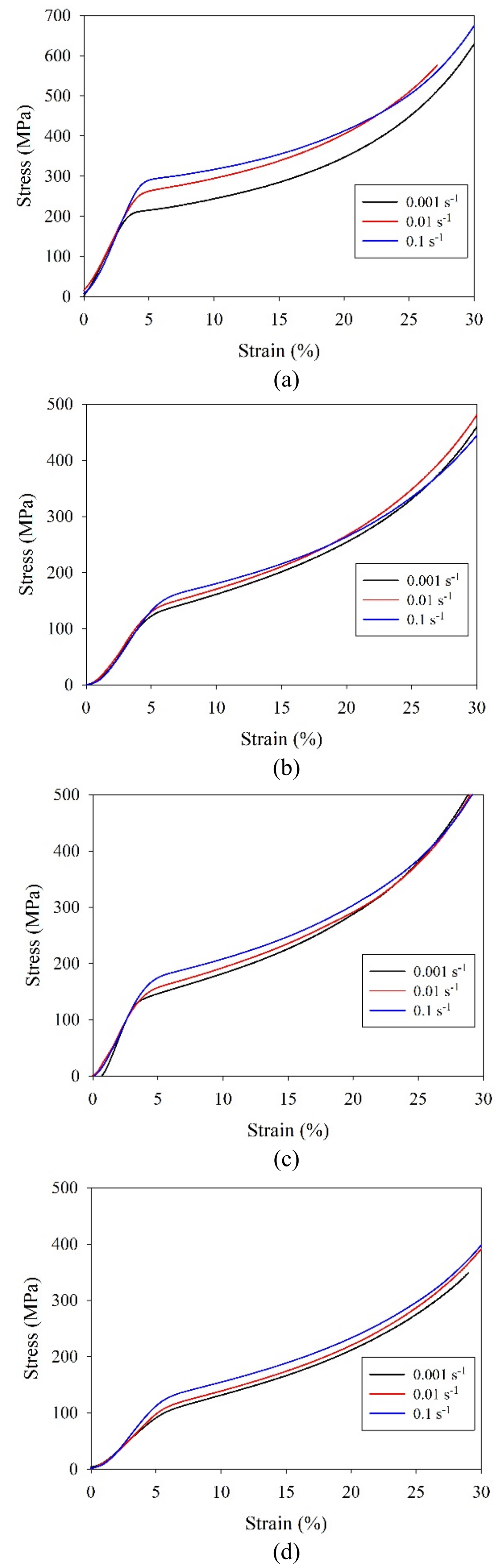


Figure 4. Effect of strain rate on compression strength of (a) neat ABS, (b) ABS90EVA10, (c) ABS80EVA20, and (d) ABS70EVA30

Table 2. Summarized mechanical properties obtained from compression tests for neat ABS and ABS/EVA blends

Materials	Strain Rate (s^{-1})	Yield Strength (MPa)
ABS	0.001	189.5
	0.01	251
	0.1	282
ABS90EVA10	0.001	128
	0.01	135
	0.1	147
ABS80EVA20	0.001	113
	0.01	120
	0.1	152
ABS70EVA30	0.001	91
	0.01	107.5
	0.1	127.5

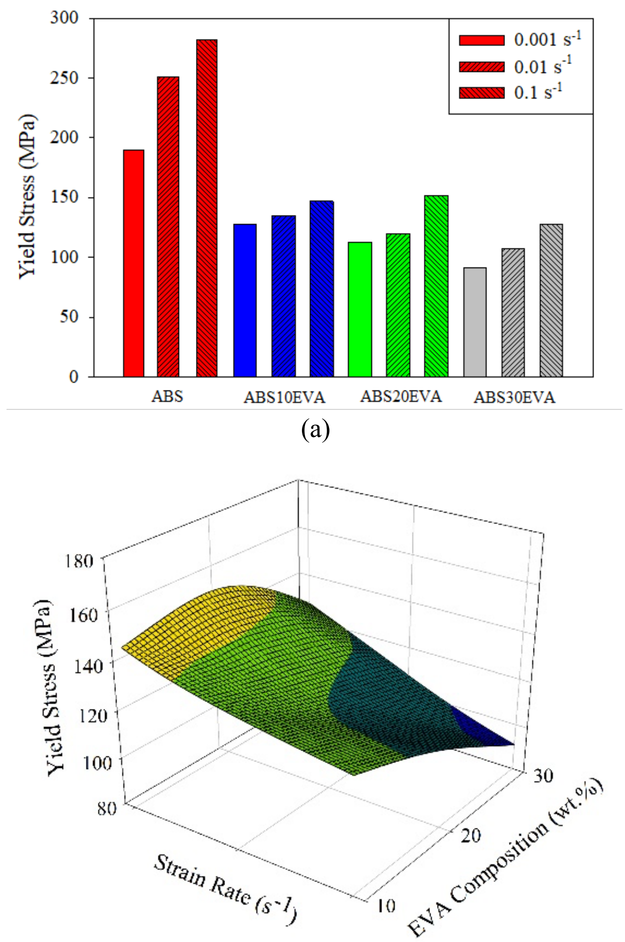


Figure 5. Compression properties of neat ABS and ABS/EVA blends, (a) strain rate effect and (b) 3D view

The stress-strain curve is a critical factor in evaluating a material's mechanical properties. Figures 4a-d summarize the compressive stress-strain curves of different polymeric blend materials under static loading rates. From the Figures, neat ABS and ABS/EVA blends shows a similar compression behavior with increase in strain rates. All tested materials showed an increasing trend in their compressive strength with increasing strain rate. The yield stress and topology graphs of neat ABS and ABS/EVA blends at different strain rates are given in Figure 5 and Table 2. It has been found that compressive strength is sensitive to strain rate, increasing as strain rate increases. The maximum compressive strength was observed for no additive at 0.1 s-1 strain rate, which is neat ABS. The curve displayed the same pattern across all strain rates [31]. In ABS/EVA blends, the yield stress decreased with EVA addition compared to the neat ABS. However, at the highest strain rate, the yield stress increased from 147 MPa to 152 MPa with ABS80EVA20 composition and decreased again to 127.5 MPa with ABS70EVA30 composition.

4. Conclusions

In this study, ABS/EVA blends with varying amounts of EVA were developed using the fused deposition modeling technique. The purpose of the study is to investigate the correlation between low strain rate values and blend ratios, rather than to demonstrate anisotropy. Further research on high strain rate values will be conducted at a later time.

The compression performance of these structures was further evaluated. The following general observations can be made:

- ABS/EVA blends with different compositions have been successfully produced using ABS and EVA copolymers.
- Experimental study samples were produced using a 3D printer with blend filaments.
- The observation of ABS/EVA blend peaks at the same point without shifting supports the compatibility and thermal stability within the structure.
- It was found that the compressive strength increased as the strain rate was increased.
- In ABS and EVA blends, the compressive strength values increase with strain rate, depending on the EVA content. The highest value is 147 MPa for ABS90EVA10, 152 MPa for ABS80EVA20 and 127.5 MPa for ABS70EVA30. The compressive strength of neat ABS was found to be 282 MPa at a strain ratio of 0.1^{-1}.
- Among the blends, at the highest strain rate value, the highest compression resistance was determined in ABS80EVA20 blend. It is noteworthy that incorporating only 20 wt.% EVA can confer ductility to ABS without significantly compromising its stiffness and strength.

Author contributions

Selahattin Budak: Investigation, Methodology, Writing - original draft, Writing - review & editing

Hamdi Kuleyin: Preparing samples, Testing, Data curation, Formal analysis, Writing - original draft

Recep Gümrük: Supervision, Resources, Writing review & editing.

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