THE INFLUENCE OF TURMERIC MICROPARTICLES AMOUNT ON THE MECHANICAL AND BIODEGRADATION PROPERTIES OF CORNSTARCH-BASED BIOPLASTIC MATERIAL: FROM BIOPLASTIC LITERATURE REVIEW TO EXPERIMENTS F. Triawan^{1*}, A.B.D. Nandiyanto^{2**}, I.O. Suryani¹, M. Fiandini², B.A. Budiman³

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Abstract. The purpose of this study was to investigate the effects of turmeric microparticles amount on the mechanical and biodegradation properties of cornstarch-based bioplastic material. To produce the bioplastics, several steps were done sequentially: (1) dissolving a mixture of cornstarch, glycerol, and acetic acid in aqueous solution; (2) adding turmeric microparticles with a specific amount (i.e., 0.50; 0.75; 1.00; 1.50% (w/w)); (3) homogenizing the mixture at temperature of 60°C; (4) molding process; and (5) drying process to get a solid bioplastic. Experimental results showed that the addition of turmeric microparticles could change the bioplastics strength as well as its biodegradability, while too much amount of turmeric may result in high strength but low biodegradability.

Keywords: bioplastics, biodegradation, cornstarch, turmeric, mechanical properties

1. Introduction

Plastics have been widely used in many fields of applications (e.g., mulch films, greenhouse, construction materials, packaging material, etc.) because of their low cost, ease of manufacture, versatility, and resistance to water [1]. During the last 10 years, world plastic production has been reported to reach 359 tons in 2018. Amount of plastic waste continues to increase over the years and is considered to cause serious environmental problems. Plastic is mostly made from synthetic polymers (i.e., polypropylene, polystyrene, and poly (vinyl chloride)) derived from petrochemicals, which are difficult to degrade by microbes in the environment [1]. Usually, the degradation of these materials takes time up to 1,000 years to decompose in landfills by breaking the carbon chain [2].

Efforts have been made to overcome the problems arising from plastic waste. However, these efforts create new issues in the environmental and health [2]. The accumulation of plastic waste greatly disrupts the circulation of air to and from the ground because plastic materials generally have high barrier properties to O_2 and CO_2 permeability [3]. Burning plastic waste produces harmful substances such as dioxins, furans, and benzopyrene (a poisonous gas), causing cancer and damage the immune system[4]. In contrast, recycling plastic waste is very expensive and less effective.

To create a sustainable environment and prevent the harmful effects of environmental problems caused by plastic waste, the production of bioplastics has received a lot of attention [5]. Bioplastics are environmentally friendly plastics made from renewable polymer materials or biomass such as starch, vegetable oils, fruit waste, lignin, cellulose, and animal origin materials such as proteins and lipids [6]. The resulting bioplastics become biodegradable plastics, which are considered efficient in replacing the use of synthetic plastics. Starch is one of the most promising materials for the fabrication of bioplastics, mainly because it is easily degraded, inexpensive, abundant, and renewable [7].

The fabrication of starch-based bioplastics has been successful and widely developed. The most recent reports on the synthesis of bioplastics are represented in Table 1. However, when using bioplastic from starch without a reinforcing agent, the resulting bioplastic interactions still have disadvantages, such as not being resistant to water and low mechanical properties [8]. To overcome this problem, in the fabrication of bioplastics, other biopolymer additives are needed to improve the mechanical properties of the bioplastic. Reporting on bioplastics with additional reinforcing agents is essential for understanding the further development of bioplastics, including knowing what additives are compatible with pure bioplastics. Table 1 shows the results of bioplastic synthesis researches that have been done previously. Those research topics are usually focusing on enhancing the mechanical properties of the bioplastics.

One of the potential reinforcing agents is turmeric. Turmeric also gives an advantage in providing a yellow color to the final product. Here, the purpose of this study was to investigate the effect of the number of turmeric microparticles on the mechanical properties and biodegradation of cornstarch-based bioplastics. Turmeric was chosen as an additional reinforcing agent because there is an antimicrobial activity potential as an antimicrobial plastic and its water-insoluble nature resulting in a water-resistant bioplastic [9]. The addition of turmeric microparticles may improve the mechanical properties because it has extraordinary interfacial interactions in the polymer. In addition, bioplastic fabrication with turmeric as a reinforcing agent has not been widely reported. This information is critical to bring benefits to the further development of bioplastic.

2. Material and Method

Preparation of bioplastic. In this study, we used micron-sized cornstarch as a basis for the bioplastic materials. Several chemicals used in the experiment were acetic acid (25%), glycerol (95%), and distilled water. For the reinforcing agent, turmeric (*Curcuma Litonga*) was sliced, washed with water to remove impurities, and dried to remove water at 60°C using an electric furnace at atmospheric pressure. Then, the dried turmeric was put into a saw-milling process to transform it into powder form with a rotation speed at 18,000 rpm. To get a homogenous milling process, the saw-milling process was done three times, in which each milling has proceeded in 5 minutes. Detailed information about the preparation of curcumin and the apparatuses are explained in our previous studies [10,11].

Fabrication of bioplastics with the addition of turmeric was done through the following steps. In the initial stage, cornstarch, acetic acid, and glycerol were mixed with a composition ratio of 3:1:3. Then, the mixture was added specific size of turmeric powder 0.50; 0.75; 1.00; and 1.50% (w/w), and stirred manually until homogeneous. Simultaneously, with the manual mixing process and process gelatinization, the mixture was heated at 60°C for 30 minutes using an electrical heater to obtain a viscous product. The viscous product was molded and dried at room temperature for more than 24 hours until it forms a solid yellow film.

Table 1. Reports	on the synthesis of biopiasi		
Type of	Raw material	Results	Ref.
carbohydrate			
Cassava starch	Cassava starch, kaolin,	The bioplastic with addition kaolin	[12]
	and metakaolin	decreases young's modulus. However,	
		bioplastic with the addition metakaolin	
		increases Young's modulus from 19 to	
		25 MPa.	
	Fresh tilapia bones,	The best bioplastic with addition 2%	[13]
	modified tapioca flour,	chitosan and 5% gelatin concentration	
	chitosan, gelatin, 6%	with value tensile strength 19,05 MPa,	
	hydrochloric acid (HCl),	percent elongation 28.33% and	
	1% acetic acid	degraded in the soil for 14 days	
	(CH ₃ COOH), glycerol,		
	distilled water		
	Potassium persulfate	Compared without cellulose, bioplastic	[14]
	(KPS), palmitic acid,	with cellulose had the good tensile	
	and dimethyl sulfoxide	strength	
	(DMSO), Ferrous		
	ammonium sulfate		
	(FAS) hexahydrate,		
	cellulose, tapioca starch,		
	and citric acid		
	Cassava starch,	The bioplastic with the addition of 4%	[15]
	precipitated calcium	PCC optimizes tensile strength and	
	carbonate (PCC), and	increases thermal stability	
	glycerol		
	Cassava starch, sugar	6% of SPF gave best tensile strength	[16]
	palm fiber (SPF),	and young's modulus up to 20.7 and	
	distilled water, and	1114.6 MPa	
	plasticizer		
	Tapioca starch, NaNO ₃ ,	The concentration of 15% GO has the	[17]
	H_2SO_4 , KMnO ₄ ,	highest tensile strength of 3.92 MPa,	
	distilled water, H_2O_2 ,	elongation of 13.22%, and modulus	
	and glycerol	young of 29.66 MPa.	51.01
Sago starch	Chicken feather,	The addition of the reinforcement (lime	[18]
	Natrium Hydroxide	juice) effectively improve the tensile	
	(NaOH), Chloride Acid	strength	
	(HCI), sago starch,		
	glycerol, and lime juice		F101
	Sago starch, glycerol,	The concentration of CMF 15% has the	[19]
	NaOH, KOH, NaCl O_2 ,	highest tensile strength of 10,23 MPa.	
	acetic acid, and H_2SO_4	However, compared bioplastic with	
		CMF, bioplastic without CMF was	
XX71 (1 (more rapidly degraded	[00]
wheat gluten	wheat gluten, Fish	Compared without fish, bioplastic with	[20]
	waste (<i>Lates calcalifer</i>),	iisn nad nign tensile strength (6.5-	
	water, and grycerol	(.5 Fa) and good dispersion.	

Table 1. Reports on the synthesis of bioplastic

Table 1. (continue) Reports on the synthesis of bioplastic

	b) Reports on the synthesis	or brophablie	
Type of	Raw material	Results	Ref.
carbohydrate			
Cornstarch	Biopolymer	The addition of natural fibers (cotton,	[21]
	(cornstarch), glycerol,	jute, hair, and wool) increase tensile	
	de-ionized water, 5%	strength	
	acetic acid solution,		
	natural fibers like		
	cotton, jute, hair, and		
	wool.		
	Cornstarch, rice straw,	The addition of the reinforcement	[22]
	sodium hydroxide,	(cellulose nanocrystal) improves the	
	sodium hypochlorite,	tensile strength and young's modulus.	
	cellulose nanocrystal	However, the percent elongation of	
	(CNC), glycerol,	bioplastic decreases	
	sulfuric, acid, and acetic		
	acid		
	Cornstarch, glycerol,	The bioplastic tensile strength was	[23]
	white vinegar, titanium	increased from 3.55 to 3.95 MPa with	
	dioxide nanoparticles	the addition of TiO ₂ . It also increases	
	(TiO_2) as reinforcing	the decomposition temperature with	
	agents	homogeneous morphology and viewer	
		cracks.	
	cornstarch (CS),	Compared without eggshell, bioplastic	[24]
	distilled water, eggshell	with eggshell improved the tensile	
	powder (ESP), and	strength, elongation et break, and water	
	glycerol	vapor	
	Cornstarch, polylactide,	Cornstarch decreased the thermal	[25]
	lysine diisocyanato,	stability of bioplastic. LDI increased	
	(LDI), and glycerol	the temperature of thermal degradation	
		(compared to bioplastic without LDI)	
		and decreased biodegradability. LDI	
		allowed a homogeneous surface	
		morphology	
Banana starch	Banana starch was	Bioplastics with the addition of 3%	[26]
	derived from green	ZnO increase the tensile strength up to	
	banana, glycerol	36 MPa. On the contrary, an elongation	
	purchased, chitosan, de-	and swelling percentage decrease with	
	acetylation, ZnO	increasing concentration of ZnO	
	powder, NaOH, glacial		
	acetic acid		
Cassava peel	Cassava peel, sorbitol,	MCC increases the tensile strength of	[27]
	and microcrystalline	bioplastic. It was reported that the	
	cellulose (MCC)	addition of 6% MCC has the highest	
		tensile strength. However, it decreased	
		elongation, density, and water	
		absorption.	

		of otoplastic	DC
Type of	Raw material	Results	Ref.
carbohydrate			
Potato starch	Sodium hypochlorite,	Compared with bioplastics chitosan,	[28]
	glycerol, acetic acid	bioplastic with eggshell improved	
	chitosan (shrimp shells)	tensile strength and good	
	potato starch, and	biodegradability	
	eggshells		
Bamboo	Bamboo	Tensile strength of bioplastics with	[29]
	(Dendrocalamus asper),	optimal conditions at 5% of	
	cellulose, toluene-	microfibrils and 3% of potassium	
	alcohol solvent.	chloride	
	potassium chloride, and		
	hydrogen peroxide		
Tamarind seed	Tamarind seed	Bioplastic with the addition of	[30]
Tamarina seed	microcrystalline	Microcrystalline cellulose optimization	[50]
	cellulose ethanol	machanical properties	
	NaOH and glugarel	meenamear properties	
	NaOII, and gryceroi		
Jackfruit seed	Jackfruit seeds, Cocoa	The ratio of bioplastic starch with the	[31]
starch	pod husk distilled water	addition of microcrystalline cellulose to	[01]
(Artocarpus	(H ₂ O) Sodium	have the best mechanical properties is	
(Ariocurpus hotoronhyllus)	Hydroxide (NaOH)	8.2 It possesses 0.637 MPa tensile	
neterophytius)	Sodium Humophonito	o.2. It possesses 0.057 WF a tensile	
	Sourilli Hypochionte	strength and an extension of 7.04%.	
	(NaOCI), Acid Chloride		
	(HCI)		
Avocado seed	Avocado seed,	The ratio of bioplastic avocado seeds	[32]
	microcrystalline	with the addition of microcrystalline to	
	cellulose, glycerol,	have the best mechanical properties is	
	hydrochloric acid,	7:3. It possesses 2.74 MPa tensile	
	potassium hydroxide,	strength and an extension of 3.61%.	
	Sodium hypochlorite,	The Bioplastic surface morphology is	
	sugar palm fibers, and	uneven and hollow	
	water		
Durian seed	Durian seeds, ultrapure	The mechanical properties test result of	[33]
	water, chitosan, acetic	bioplastic from durian seeds are still far	
	acid (0.10%) . and lime	from the standard when it is compared	
	water	with the moderate bioplastic. It has a	
		tensile strength of 0 1158 MPa while	
		the standard has an elongation of	
		2 1875% and Young's modulus of	
		4 1515 MD	

Table 1. (continue) Reports on the synthesis of bioplastic

Physicochemical properties. The prepared bioplastic was characterized using a Digital Microscope (BXAW-AX-BC, China) to analyze the chemical structure and particle morphology, respectively. To support the analysis, we conducted characterizations using a Fourier Transform infrared (FTIR-4600, Jasco Corp., Japan) to the prepared bioplastic.

Mechanical properties. The compression test was performed using 313 Family Universal Test Machine with a loading rate of 1 mm/sec at 24°C and humidity of 10%. The samples were tested for the compression test having a variable dimension, as shown in

(1)

Table 2. Before the test was carried out, the samples were measured using a Vernier caliper, and the compression plate was coated with Vaseline jelly as the lubricant to reduce the friction effect. Data collected from compression tests such as the load-displacement curves and the stress-strain curves were evaluated from each sample to analyze its mechanical properties, i.e. Young's modulus and ultimate strength.

Bioplastic with specific amount turmeric, % (w/w)	Dimension, cm
0.50	2×2×0.6
0.75	2×2×0.6
1.00	1.5×1.5×0.5
1.50	1.5×1.5×0.5

1 auto 2. Samples unitensity	Table 2	Sam	ples	dimer	ision
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The following formula can be used to process the raw data from the compression test for further analyses:

(1) Ultimate compressive strength (S_{ucs}) is defined as the maximum force that can be held in the sample when being compressed before the material is broken. The ultimate compression strength can be calculated by dividing maximum stress (F_M ; N) with the cross-section area of the specimen (A; mm²)) as shown in Eq. (1) [34].

$$S_{ucs} = \frac{F_M}{A}.$$
(2) Young's modulus (E) is a mechanical property that measures the stiffness of elements of the stiffness of the stiff

(2) Young's modulus (E) is a mechanical property that measures the stiffness of elastic deformation of the specimen under a given load. Young's modulus can be obtained from the slope of the stress-strain since defines the relationship between stress (σ) and strain (ε) of material deformation in the linear elasticity regime. Young's modulus can be determined using Eq. (2) [34].

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1},$$
(2)

where ε_1 and ε_2 are the condition of relative elongation, and σ_1 and σ_2 are the stress that occurs at ε_1 and ε_2 , respectively. The method of observing the slope-strain of the sample for defining Young's modulus is adopted since the slope of the sample can be directly observed as a function of the material deformation (strain).

Biodegradability. The biodegradability tests were conducted by slicing the prepared bioplastics with sizes of about $5 \times 5 \times 5$ mm and then immersing them into ultrapure water. The weight losses of the sample were measure at the interval time of two days. In line with this test, during the immersing process, it was also visually observed the change of color. Detailed information about the biodegradability test is reported in our previous study [35].

3. Results and Discussion

Figure 1 is a photograph of a bioplastic fabrication with the addition of the amount of turmeric. The addition of turmeric gives the bioplastic end product its yellow color. The amount of turmeric added affects the physical condition of the bioplastic, where the bioplastic with a higher amount of turmeric causes the bioplastic to crack (see Figs. 1 (a) 0.50; (b) 0.75; (c) 1.00; and (d) 1.50% (w/w)).

To clarify the bioplastic structure, a microscope analysis was conducted (See Fig. 2). The results in Figs. 2(a) and (b) are the appearances of the micron-sized cornstarch and turmeric powder that has been prepared. Micron-sized cornstarch is a white crystal, solid and dense. Turmeric powder is a yellow color, heterogeneous surface, and agglomerate. Figure 2(c), (d), (e), and (f) are bioplastics with addition of specific amount of turmeric of 0.50; 0.75; 1.00; and 1.50% (w/w), respectively. Bioplastics with the addition of a higher amount of turmeric have a more heterogeneous surface and agglomerates, making them more brittle and

104

stiffer. Figure 2(g) is the appearance of the bioplastic after being immersed for two weeks in water. The color of the bioplastic starts to change from yellow to brownish-yellow. It can be seen that after two weeks of immersion, cracks are found due to the swelling phenomenon. Figure 2(h) is the appearance of the bioplastic after being immersed for four weeks in the water in which fungi grow significantly.



Fig. 1. Photograph image of cornstarch-based bioplastics with the addition specific amount turmeric (a) 0.50; (b) 0.75; (c) 1.00; and (d) 1.50% (w/w)



Fig. 2. Microscope image of sample: (a) micro-sized cornstarch, (b) agglomerated turmeric powder, (c-f) bioplastic with specific amount turmeric ((c) 0.50; (d) 0.75; (e) 1.00; and (e) 1.50% (w/w)), (g) bioplastics after two weeks immerged in water and (h) fungi bioplastic after four weeks immerged in water

To confirm the phenomenon during the immersion process, Fig. 3 shows the results of the FTIR analysis of as-prepared bioplastics, bioplastics immersed for two weeks in water, and the surface of the bioplastic samples immersed for four weeks. Data were then compared with the standard FTIR analysis [36]. The as-prepared bioplastic results were identified at wavelengths 1022, 1647, and 3280 cm⁻¹. A comparison of FTIR peaks for bioplastics before and after two weeks of immersion in water confirms that biodegradability in water is simply a dilution of the outer components of the bioplastic. The reaction between water and bioplastics involves a dilution process and does not interfere with complicated reactions. We also found that in the FTIR spectra of bioplastics after four weeks of immersion, the absorption peak

experienced a decrease in intensity, indicating degradation that changed the chemical structure of bioplastics due to fungal activity.



Fig. 3. FTIR analysis results of as-prepared bioplastic, 2-week immerged bioplastic in water, and fungus on the 4-week immerged sample

A biodegradability test of bioplastic samples with different turmeric amounts was carried out by immersion method [35]. It was evaluated by analyzing the mass of the bioplastics as a function of days. Table 3 shows the results of the bioplastic reduction performed for two weeks. The analysis showed that the sample with 0.50% (w/w) of turmeric had the best biodegradability, which was indicated by a weight loss of 86% for two weeks. The possible weight loss during 2-week immersion is because the bioplastics' outer surfaces were diluted in water, which was confirmed by the identical FTIR patterns. This result is different for 2-week immersion bioplastic, in which the mass loss was followed by the appearance of fungus (see Fig. 2(h)) and fungus chemical structure (see Fig. 3). The present bioplastics were made from cornstarch, making microorganisms to break the polymer chain easily inside the bioplastic shower than that of bioplastic made from starch without additional curcumin [36]. The main reason is that the curcumin creates an antimicrobial agent, slowing the growth of microbes in degrading the bioplastic.

Figure 4 is a two-dimensional illustration model of particle crack during mechanical testing. The blue square and yellow circle represent the cornstarch and turmeric particle, respectively. The amount of turmeric added to the bioplastic fabrication process directly affects the mechanical and physical properties of the bioplastic. Due to the nature of a crack, the initiated crack propagates toward the turmeric particles because of the relatively low stiffness than cornstarch (see Fig. 4(a)) [38]. Furthermore, the bonding between cornstarch and turmeric is relatively low and easy to break [39]. This means the addition of turmeric particles are quite a lot, a polymerization between turmeric particles might occur, resulting in a higher stiffness of polymerized turmeric particles (see Fig. 4(c)). As a consequence, the initiated crack tends to avoid the polymerized turmeric particles. To confirm these phenomena, compressive test for different turmeric amount was conducted.

Table 3. Weight loss bioplastics with the addition of a specific amount of turmeric during the immersion process

0.50%	Days	Initial	Initial	Mass after	Mass loss,	Decay
(w/w)	-	Dimension,	mass,	Immersion,	wt%	dimension,
		cm^2	g	g		g/cm ²
	1	1.316	0.150	0.113	24	0.030
	2	1.311	0.093	0.043	55	0.039
	4	1.120	0.107	0.037	66	0.063
	6	1.254	0.133	0.040	71	0.075
	8	1.181	0.153	0.040	74	0.096
	10	1.283	0.143	0.027	81	0.092
	14	1.460	0.143	0.020	86	0.088
0.75%	Days	Initial	Initial	Mass after	Mass loss,	Decay
(w/w)		Dimension,	mass,	Immersion,	wt%	dimension,
		cm^2	g	g		g/cm ²
	1	1.089	0.130	0.087	33	0.040
	2	1.364	0.127	0.077	40	0.039
	4	1.203	0.140	0.067	53	0.070
	6	1.071	0.147	0.057	61	0.085
	8	1.214	0.133	0.050	63	0.069
	10	0.939	0.107	0.037	66	0.075
	14	1.145	0.0133	0.037	73	0.086
1.00%	Days	Initial	Initial	Mass after	Mass loss,	Decay
(w/w)		Dimension,	mass,	Immersion,	wt%	dimension,
		cm^2	g	g		g/cm ²
	1	1.106	0.147	0.090	39	0.052
	2	1.146	0.143	0.080	44	0.055
	4	0.887	0.127	0.063	50	0.071
	6	1.070	0.133	0.053	60	0.076
	8	1.038	0.140	0.053	62	0.085
	10	1.103	0.153	0.053	65	0.095
	14	1.101	0.143	0.043	70	0.093
1.50%	Days	Initial	Initial	Mass after	Mass loss,	Decay
(w/w)		Dimension,	mass,	Immersion,	wt%	dimension,
		cm ²	g	g		g/cm ²
	1	1.378	0.137	0.103	24	0.025
	2	1.006	0.120	0.063	48	0.065
	4	1.192	0.110	0.047	57	0.057
	6	1.168	0.127	0.047	63	0.072
	8	1.276	0.123	0.043	65	0.063
	10	1.433	0.130	0.043	67	0.061
	14	1.249	0.130	0.040	69	0.075



Fig. 4. Illustration progression cracking of bioplastic for (a) low density of turmeric, (b) high density of turmeric, and (c) high density of turmeric with polymerization

Figure 5 shows the plot of stress-strain data of the bioplastic sample from the compression test. Refer to Fig. 4, it can be observed that the stress-strain curve of each sample shows a similar trend by showing the elastic deformation region and followed by the ultimate stress (peak stress). The observation will be focused on the ultimate strength as it represents the maximum compression force per unit cross-section area that the sample can survive before breaking up.

To observe the ultimate strength of each sample, the stress-strain plot was particularly limited to the strain of 0.6 and stress of 2250 kPa, as presented in Fig. 6. The ultimate strength values can be then determined as shown in Table 4. The ultimate strength values of samples of 0.50; 0.75; and 1.00% (w/w) were 1059.0; 941.2; and 375.8 kPa, respectively, showing a decreasing trend of strength with increasing turmeric addition. It decreased because the turmeric particle has low stiffness and low bonding strength with cornstarch. As a result, it fastens the crack propagation and resulting in lower compressive strength. However, sample 1.50% (w/w) shows a different behavior of having the ultimate strength of 1957.0 kPa. It might be due to the high turmeric content in the material, which increased the potency of turmeric particles to do the polymerization process (see Fig. 4(c)), causing a higher stiffness. The high stiffness can resist crack propagation inside the bioplastics. This behavior was then confirmed by observing Young's moduli values of each bioplastic sample under compressive load.



Fig. 6. Stress vs strain of bioplastic samples limited at strain 0.6 and 2250 kPa, respectively

Bioplastic with the addition of specific amount turmeric, %	Ultimate strength,
(w/w)	kPa
0.50	1059.0
0.75	941.2
1.00	375.8
1.50	1957.0

Table 4. Ultimate strength of bioplastic samples

The amount of turmeric affects the stiffness of the sample as the higher turmeric amount may lower the intermolecular bonding that results in a heterogeneous sample structure. It causes the stiffness of the material to decrease. This is related to fiber interaction [40] and polymerization [35]. As the result, the measured Young's modulus decreased with increasing turmeric content. These phenomena are shown in Fig. 7, in which the slope of the stress-strain curve of each sample represented Young's modulus. Based on the plot, Young's moduli of bioplastic samples of 0.50; 0.75; and 1.00% (w/w) were concluded to be 13090, 13000, and 7500 kPa, respectively (see Table 5). However, the bioplastic sample with a turmeric amount of 1.50% (w/w) showed a different trend of having two peaks. It may be correlated with the polymerization of between turmeric particles in the sample (see Fig. 4(c)), therefore the rupture characteristics affect the instability during the compression test including the stress-strain curves [41]. Hence, the stress-strain curve showed different trends of having two peaks of the slope.



Fig. 7. Slope of stress-strain curves vs. strain of bioplastic specimens

The influence of turmeric microparticles amount on the mechanical and biodegradation properties of...

Bioplastic with specific amount turmeric,	Young's Modulus,
% (w/w)	kPa
0.50	13090
0.75	13000
1.00	7500
1.50	22083

Table 5. Ultimate strength of bioplastic samples

5. Conclusion

The present work investigated biodegradability and the mechanical properties of cornstarchbased bioplastic materials by incorporating the effect of turmeric microparticles number. Based on FTIR analysis, the bioplastic soaked in water for two weeks does not demonstrate any chemical reactions, which means the dissolving process mainly causes the loss of bioplastic weight. In contrast, the bioplastic left for four weeks shows a chemical reaction caused by fungi activity. From the compressive test results, it was revealed that, for turmeric of from 0.50 to 1.00% (w/w), increasing the turmeric amount resulted in decreasing the ultimate strength value. This was likely due to the bonding between cornstarch and turmeric particles relatively weak. Furthermore, the low Young' modulus was recorded as the number of turmeric particles is high. It indicates the turmeric particles has lower rigidity than the cornstarch matrix. Due to the nature of the cracks, which always propagate to particles having lower rigidity, the bioplastic will crack more easily for higher turmeric particles. Thus, in the range of turmeric of 0.50 to 1.00% (w/w), the highest ultimate strength and highest Young's modulus of bioplastic sample were achieved by sample 0.50 (w/w) i.e. 1059 and 13090 kPa, respectively. However, different phenomena appeared for turmeric of 1.50%, in which the ultimate strength and Young's modulus drastically increase i.e. 1957 and 22083 kPa, respectively. The turmeric particles are sufficient to create polymerization which causes the rigidity of turmeric particles to increase significantly. Thus, the crack propagates slowly in the bioplastic. The determination of turmeric amount in creating the cornstarch-based bioplastic is essential to assure the mechanical properties and biodegradability are as designed.

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