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Amplification Ratio of a Recycled Plastics-Compliant Mechanism Flexure Hinge

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Abstract: This research focuses on the fabrication of plastic flexure hinges from diverse plastics such as ABS, PP, HDPE, and LDPE. To enhance hinge efficiency, the recycling ratios are also investigated. The amplification ratio of different recycle ratios and plastic types are measured. The results show that the input and output displacements of all PP, ABS, and HDPE hinges are linear. The presence of recycled plastics has no impact on this basis. The pure PP, ABS, and HDPE flexure hinges achieve the highest amplification ratios of 5.728, 8.249, and 5.668. The addition of recycled plastics reduces the amplification ratio. This decrease in the amplification ratio, however, is small. At a 25% recycle ratio, the PP, ABS, and HDPE flexure hinges have 12%, 13.3%, and 21.7% lower amplification ratios than the pure plastic hinges. Furthermore, the utilization of recycled plastics may lessen the need for new plastic made from raw materials. With the PP flexure hinge, a maximum input value of 157 µm could result in an output value of 886 µm. At a maximum input value of 115 µm, the ABS flexure hinge could achieve an output value of 833 µm. Finally, a maximum input value of 175 µm might result in an output value of 857 µm when using the HDPE flexure hinge. The average amplification ratio values for all recycling ratios for PP, ABS, and HDPE flexure hinges are, respectively, 5.35, 7.60, and 5.02. The ABS flexure hinge frequently outperforms the PP and HDPE flexure hinge in terms of amplification ratios. Among these plastics, HDPE flexure hinges have the lowest amplification ratio. In general, increasing the thermoplastic polyurethane (TPU) content of the LDPE/TPU blend increases the amplification ratio. The cause could be the TPU's high compatibility with the LDPE polymer. The LDPE/TPU blend hinge offers a broader range of the amplification ratio of 2.85–10.504 than the PP, ABS, and HDPE flexure hinges. It is interesting that changing the blend percentage has a much greater impact on the amplification ratio than changing the recycling ratio. The findings broaden the range of applications for plastic flexure hinges by identifying optimal plastic types. The impact of the hinge shape on the performance of the injected plastic flexure hinge might be studied in further research.

Keywords: ABS; amplification ratio; recycle ratio; HDPE; PP; LDPE/TPU

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1. Introduction

A compliant mechanism is a flexible structure body that could transfer force, momentum, and movement based on the elastic deformation of the body [1–3]. The compliant mechanism is widely applied in robotics, precision devices, aerospace, and consumer products due to the advantages of no friction force and backlash [4–6]. During the loading process, the compliant mechanism structure is deformed, therefore, storing the elastic energy. After that, the energy in the compliant mechanism structure is released to perform its purpose [7–9]. There are many structural types of compliant mechanism structures such as beam flexures, shell flexures, sheet flexures, and combination structures [10–13].

A compliant mechanism structure can be used as a compliant flexure hinge for amplifier application in precision engineering. There are many types of compliant flexure hinges for amplifiers, for instance, elliptical type, notch type, circular type, and bridge type [14–17]. A bridge-type-compliant flexure hinge possesses the merits of a high ratio of the output displacement to the input displacement, a simple structure, and can suffer a high load. To design compliant flexure hinges, besides considering the hinge geometry, materials selection and manufacturability are also critical factors. For example, a compliant flexure hinge generated from conventional metallic materials is reliable but demands a complex process of manufacturing. A metallic flexure hinge is usually created by an electrical discharge machine (EDM), a wire-cutting machine, a 3D printing machine, or a laser cutting machine [18–21]. For example, Liu et al. [22] generated a triple-cross-spring flexure pivot in a wire-cutting machine. This flexure pivot achieves a large motion stroke and high precision; however, the assembly process could lead to a remarkable error. Wang et al. [23] rapidly produced a flexure hinge using a 3D printing machine combined with a wire cutting machine. Initially, the body of the flexure hinge is printed by a selective laser melting 3D printer. Thereafter, the body is machined via a precision wire-cutting machine. Coemert et al. [24] created titanium-based flexure hinges by laser cutting. The findings showed that the payload value is inversely proportional to the hinge length but proportional to hinge width.

The metallic flexure hinges often require a lot of time and cost to be created due to the complex structure and the high precision demand. Plastic-compliant flexure hinges appear to be an ideal alternative as this material is cheaper and can be more easily produced. For instance, Mutlu et al. [25] produced a 3D-printed flexure hinge using the thermoplastic elastomer (TPE) and discovered that the optimal designs are elliptic and non-symmetric. Specifically, plastic-compliant flexure hinges could be injected by an injection molding machine with high productivity. Rosa et al. [26] used the mesoscale injection molding to produce a flexure-based nanopositioner made from cyclic olefin copolymer (COC). The COC nanopositioner has a travel range of 15 µm and a maximum standard deviation of 52.3 nm. Remarkably, the recycled capacity of the plastics created a cheap substitute for metallic flexure hinges. Despite its advantages, injected plastic flexural hinge investigations are not widely used and require additional research. Recently, recycled plastics have been widely applied in many industrial fields. Even for the automotive industry, which usually requires high-quality materials, using recycled plastics is a good choice [27]. Automotive companies tend to increase the recycled plastics in their product [28,29]. Popular plastics such as ABS, PP, HDPE, and LDPE in the automotive industry have received much attention due to their high efficiency [30].

This investigation focuses on examining the injection plastic flexure hinge from the different types of polymers, including the ABS, PP, HDPE, and LDPE/TPU blend. The effect of the incorporated recycled polymer ratio was also investigated in order to maximize the hinge performance. The rates of amplification are measured and compared. The findings add to our understanding of plastic flexure hinges and widen their uses by identifying the best plastic kinds and recycle ratios.

2. Materials and Methods

2.1. Materials

The PP polymer named Advanced-PP 1100 N is supplied by the Advanced Petrochemical Company, Saudi Arabia. The ABS 750 SW polymer is manufactured by Kumho Petrochemical, Korea, while the HDPE polymer HTA 108 is imported by the Exxon Mobile Petroleum and Chemical Company, Saudi Arabia. The TPU polymer (TPU® TU90AE) is produced by Dongguan Rayan Polymer in China. LDPE polymer InnoPlus LD2426H is supplied from PPT company, Thailand. Besides examining the effects of plastic types, this study also surveys the impact of the recycled plastics ratio on the displacement rate. The recycle ratio of PP, ABS, and HDPE polymers ranges from 0% to 25%. Table 1 shows the injection mold parameters of the PP, ABS, and HDPE hinges. The ABS polymer blended with 0–25% TPU is also considered. The injection parameters in these tables are chosen based on the polymer properties, hinge shape, and injection molding equipment to ensure that they are receiving a good, injected sample. The filling speed and packing speed are expressed as a percentage of the injection machine's injection rate, which is 154 g/s. The injection molding machine type used in this study is MA 1200III, Haitian, China. The average UTS values of PP, ABS, HDPE, LDPE, and TPU are 35 MPa, 48.5 MPa, 60 MPa, 11 MPa, and 55 MPa.

Table 1. Injection the molding parameters of PP, ABS, HDPE, and LDPE/TPU flexure hinges.

Parameters	PP	ABS	HDPE	LDPE/TPU
Filling pressure (bar)	40	43	26	25
Filling speed (%)	75	75	65	60
Filling time (s)	2	2	2	2
Packing pressure (bar)	45	38	23	20
Packing speed (bar)	75	70	60	60
Packing time (s)	2	1	1	1
Temperature (°C)	200	210	205	200

2.2. Methods

The flexure hinge design, compliant mechanism, and the injected hinge are shown in Figure 1. Figure 2 shows the fixture for the hinge, and the measurement tool with chronographs for determining the hinge's displacement. The measurement process has three steps. Step 1: Attach the sample to the bracket in the correct position and attach the chronographs to the correct position. Step 2: Place the pusher in the middle of the measurement model so that it matches the measurement model and adjusts. All chronographs are set to zero. Step 3: Turn the handle on the pusher, and then observe the chronographs and record the results. These samples are injected with the sample mold; therefore, the thickness and geometries are the same. The testing process is conducted at 25 °C.

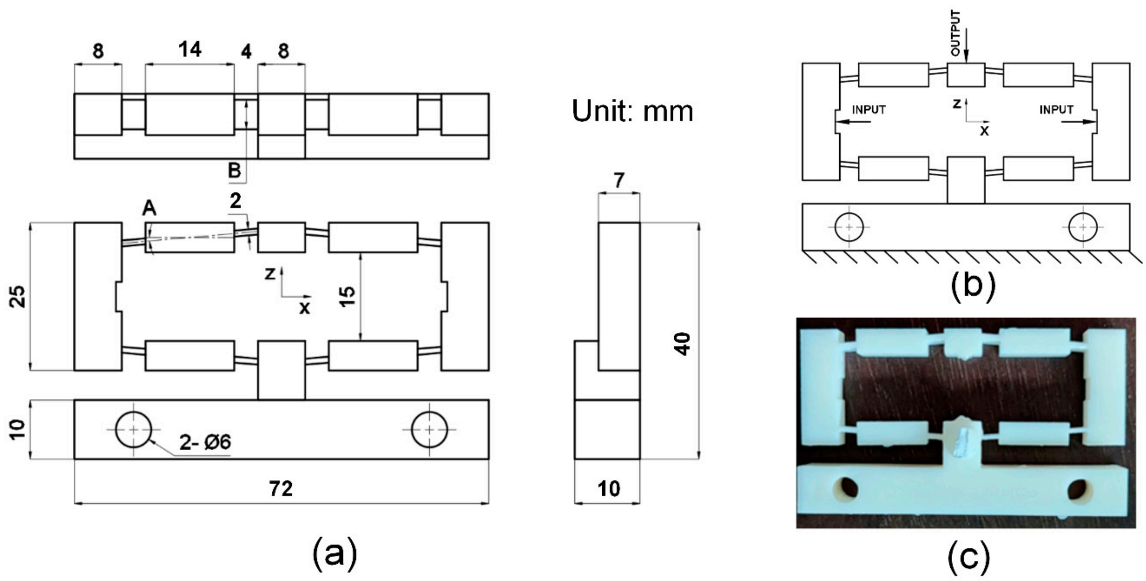

Figure 1. Plastic bridge—type flexure hinge: (**a**) 2D design; (**b**) compliant mechanism of the hinge; and (**c**) injection molding hinge.

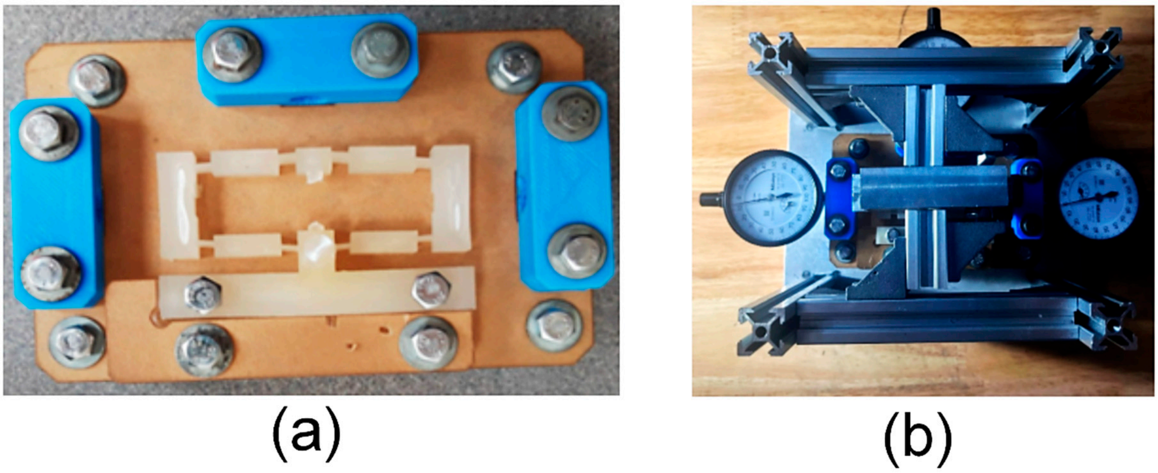

Figure 2. The fixture and measurement device of the plastic flexure hinge: (**a**) fixture; and (**b**) measurement device setup.

3. Results and Discussion

3.1. Amplification of PP, ABS, and HDPE Flexure Hinges

This section examines the effects of the recycle ratio on the displacement of the PP, ABS, and HDPE flexure hinges. Firstly, we survey the impact of the recycle ratio on the displacement of the PP hinge. For each recycle ratio, we measured five samples. The average input and output parameters of PP hinges at different recycle ratios are presented in Table 2.

Table 2. Average input and output parameters of PP hinges at different recycle ratios.

Input (µm)	0	34	53	64.5	74	86	101.5	112.5	120	132	157
Output 25% (µm)	0	98	202	294	357	425	504	572	627	691	814
Output 20% (µm)	0	100	208	298	361	434	512	600	646	713	839
Output 15% (µm)	0	109	212	301	364	438	527	615	660	726	856
Output 10% (µm)	0	112	219	308	373	458	547	620	666	741	861
Output 5% (µm)	0	121	228	312	384	487	558	626	681	764	867
Output 0% (µm)	0	145	257	339	414	498	584	651	706	797	886

Figure 3 shows the average displacement diagrams of the PP flexure hinge with various recycle ratios. With a maximum input value of 157 µm, the average output value is 886 µm, indicating the hinge's strong amplification rate. The regression equations between the average values of the input and output displacements are as follows:

$$y_1 = 5.728x_1 \quad (1)$$

$$y_2 = 5.50x_2 \quad (2)$$

$$y_3 = 5.381x_3 \quad (3)$$

$$y_4 = 5.288x_4 \quad (4)$$

$$y_5 = 5.183x_5 \quad (5)$$

$$y_6 = 5.036x_6 \quad (6)$$

where y_1, y_2, y_3, y_4, y_5, and y_6 are the output data; and x_1, x_2, x_3, x_4, x_5, and x_6 are the input data of the PP flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%, respectively.

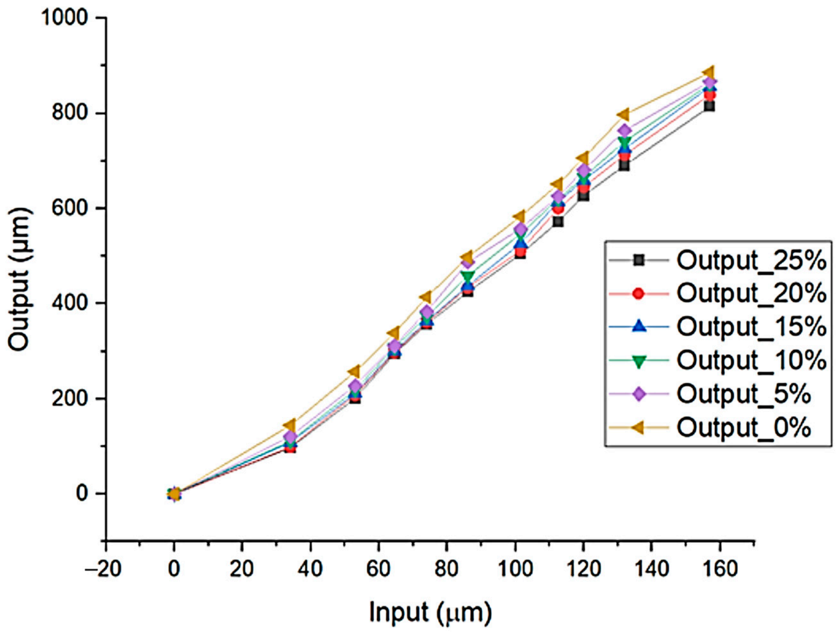

Figure 3. Average displacement diagrams of PP flexure hinge at different recycle ratios.

We created the regression equations using the trendline option in Excel software. The accuracy in these cases is calculated based on the R-square value of the trendline, which varies around 0.92–0.99. These are good enough as an R-square value of 0.9 is a good value with high accuracy. These equations show that the amplification ratio values are 5.728, 5.50, 5.381, 5.288, 5.183, and 5.03, which correspond to the PP flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%. Generally, increasing the recycle ratio leads to a slight decline in the amplification ratio. The most significant result is that raising the input value typically results in a linear increase in the output value. At recycle ratio of 0%, the PP flexure hinge achieves the highest amplification ratio of 5.728. However, at a recycle ratio of 25%, the PP flexure hinge gains the lowest amplification ratio of 5.036, which is 12% lower than the highest one. The reason for this reduction is the degradation of the recycled PP component, leading to a weaker polymer as the recycle ratio increases. The amplification ratio of the PP hinge is primarily smaller when compared to the aluminum alloy flexure hinge, which has an amplification of 41 in Chen et al.'s report [31]. The reasons are the higher strength and stiffness of the aluminum alloy and the 3D bridge-type of the aluminum alloy hinge compared to the 2D bridge type of PP plastic.

The average input and output parameters for ABS hinges at various recycle ratios are shown in Table 3. The results from Table 3 are illustrated in Figure 4. With the maximum input value of 115 μm, the average output value is 833 μm, indicating the high amplification rate of the hinge. The regression equations between the average input and output displacement values are given as follows:

$$y_7 = 8.249x_7 \quad (7)$$

$$y_8 = 7.843x_8 \quad (8)$$

$$y_9 = 7.646x_9 \quad (9)$$

$$y_{10} = 7.506x_{10} \quad (10)$$

$$y_{11} = 7.233x_{11} \quad (11)$$

$$y_{12} = 7.152x_{12} \quad (12)$$

where y_7, y_8, y_9, y_{10}, y_{11}, and y_{12} are the output data; and x_7, x_8, x_9, x_{10}, x_{11}, and x_{12} are the input data of the ABS flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%.

Table 3. Average input and output parameters of ABS hinges at different recycle ratios.

Input (µm)	0	15	27	34	41	45	55	63	70	85	115
Output 25% (µm)	0	82	141	214	285	346	436	482	550	653	739
Output 20% (µm)	0	85	164	207	281	344	435	482	568	661	748
Output 15% (µm)	0	87	174	231	285	357	444	512	599	677	771
Output 10% (µm)	0	96	181	238	286	363	457	531	624	684	773
Output 5% (µm)	0	97	189	246	305	364	467	542	643	713	783
Output 0% (µm)	0	108	204	260	324	399	489	560	666	741	833

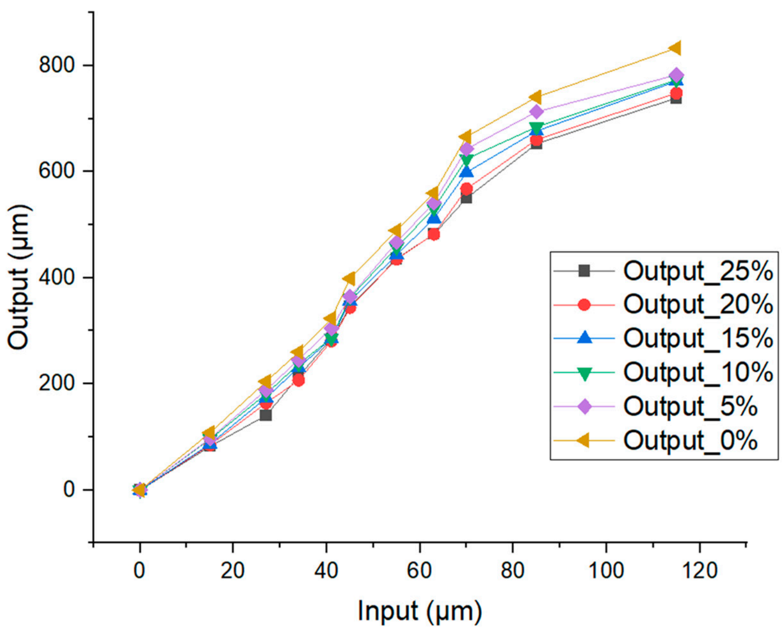

Figure 4. Displacement of the ABS flexure hinge at different recycle ratios.

The amplification ratio values are 8.249, 7.843, 7.646, 7.506, 7.233, and 7.152, which correspond to the ABS flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%. In general, raising the recycle ratio leads to a small reduction in the amplification ratio. Most notably, increasing the input value usually results in a linear increase in the output value. At a recycle ratio of 0%, the ABS flexure hinge achieves the highest amplification ratio of 8.249. However, at a recycle ratio of 25%, the ABS flexure hinge gains the lowest amplification ratio of 7.152, which is 13.3% lower than the highest one. This decrease is due to the degradation of the recycled ABS component, which results in a weaker polymer as the recycle ratio increases. Compared to the spring steel flexure hinge with an amplification of 13–15 reported by Ling et al. [32], the amplification ratio of the ABS hinge is mainly lower. The reasons are the higher strength and stiffness of the spring steel compared to the ABS plastic. Additionally, the ABS flexure hinge has a much higher amplification ratio than the PP one.

Table 4 presents the average input and output parameters of HDPE hinges at different recycle ratios. The results from Table 4 are illustrated in Figure 5. Figure 5 presents the average displacement diagrams of the different recycle ratios of the HDPE flexure hinge. With the maximum input value of 175 μm, the average output value is 857 μm, indicating the high amplification rate of the hinge. The regression equations for the average values of the input and output displacements are as follows:

$$y_{13} = 5.668x_{13} \quad (13)$$

$$y_{14} = 5.404x_{14} \quad (14)$$

$$y_{15} = 5.159x_{15} \quad (15)$$

$$y_{16} = 4.852x_{16} \quad (16)$$

$$y_{17} = 4.616x_{17} \quad (17)$$

$$y_{18} = 4.436x_{18} \quad (18)$$

where y_{13}, y_{14}, y_{15}, y_{16}, y_{17}, and y_{18} are the output data; and x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, and x_{18} are the input data of the HDPE flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%.

Table 4. Average input and output parameters of HDPE hinges at different recycle ratios.

Input (μm)	0	15	25	40	50	63	80	95	113	138	175
Output 25% (μm)	0	89	157	228	283	341	413	458	493	524	745
Output 20% (μm)	0	102	160	245	294	360	424	461	507	576	762
Output 15% (μm)	0	105	166	254	309	360	445	502	544	615	785
Output 10% (μm)	0	110	172	264	319	374	474	548	611	684	790
Output 5% (μm)	0	107	178	274	336	415	493	584	646	715	814
Output 0% (μm)	0	115	194	290	353	450	532	608	662	744	857

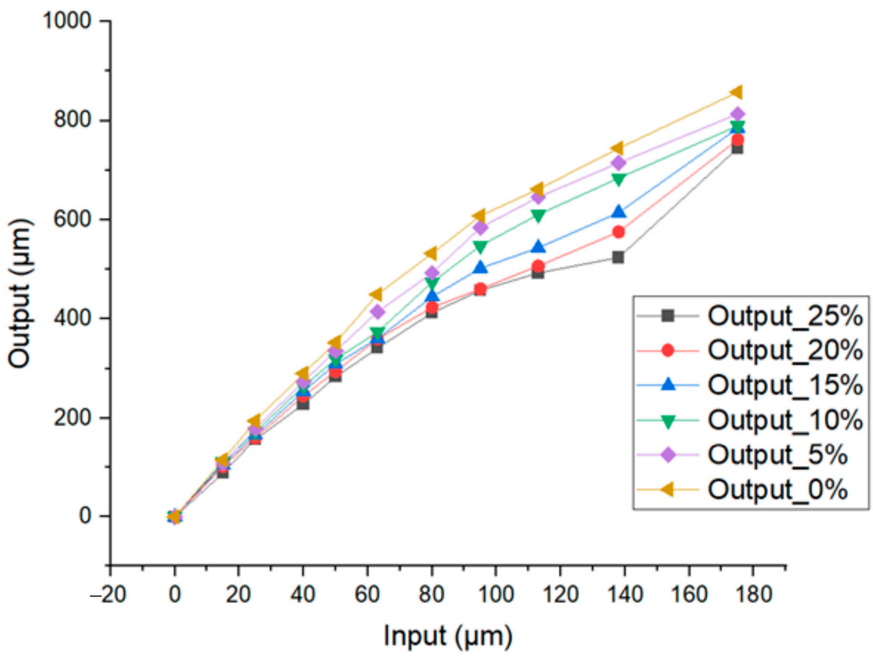

Figure 5. Displacement of HDPE flexure hinges at different recycle ratios.

The amplification ratio values are 5.668, 5.404, 5.159, 4.852, 4.616, and 4.436, which correspond to the HDPE flexure hinge at recycle ratios of 0%, 5%, 10%, 15%, 20%, and 25%. Generally, increasing the recycle ratio leads to a slight improvement in the amplification rate, which is similar to the PP and ABS cases. Most importantly, improving the input value mostly leads to a linear increase in the output value. At a recycle ratio of 0%, the HDPE flexure hinge has the highest amplification ratio of 5.668. At a recycle ratio of 25%, the HDPE flexure hinge achieves the lowest amplification ratio of 4.436, which is 21.7% lower than the highest. The amplification ratio of the HDPE hinge is primarily lower when compared to the titanium alloy flexure hinge with an amplification of 6.0 in Fiaz et al.'s work [33]. The reason for this is that titanium alloys have a higher strength and rigidity than the HDPE plastic. Additionally, the HDPE flexure hinge's amplification ratio is significantly lower than that of the ABS flexure hinge.

Overall, all the PP, ABS, and HDPE hinges have linear relationships between the input and output displacement. This principle is unchanged by the presence of recycled plastics. Additionally, adding recycled plastics causes the amplification ratio to decrease. This decrease in the amplification ratio, however, is small. At a 25% recycle ratio, the PP, ABS, and HDPE flexure hinges gain an amplification ratio that is 12%, 13.3, and 21.7% lower than the pure plastic hinges. Additionally, using recycled plastics could reduce the need for new plastic made from raw materials.

3.2. Comparison between PP, ABS, and HDPE Flexure Hinges

In this section, the displacements of the HDPE are compared with the previous results of the ABS and PP flexure hinges. The input and output equations at different recycle ratios are presented in Table 5. Figure 6 shows a more visual representation of these results.

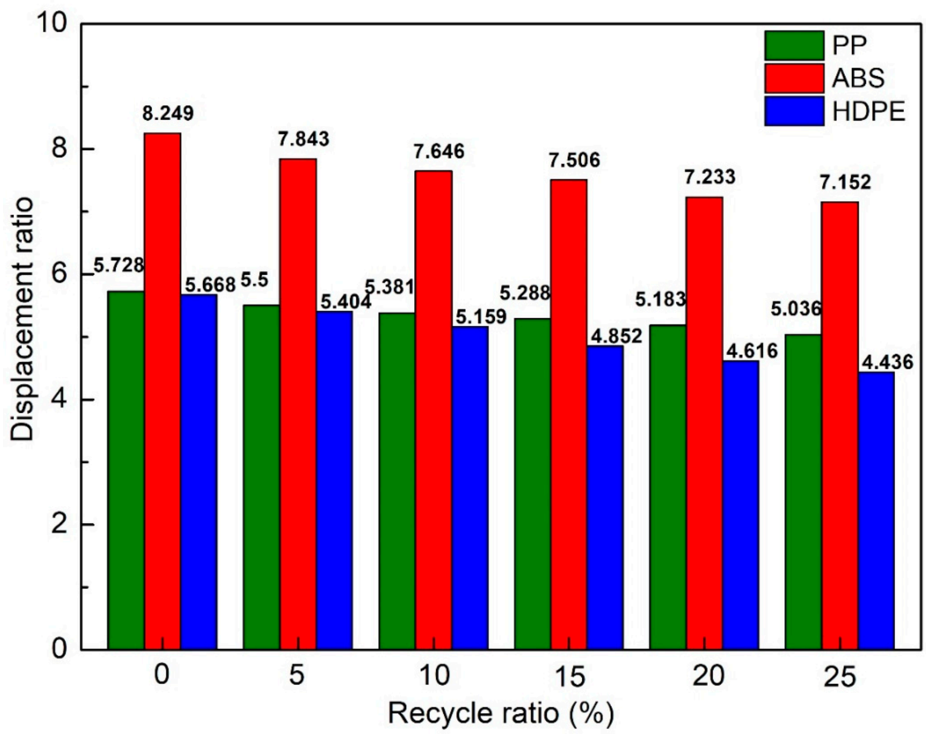

Figure 6. Comparison between the displacement ratios between the PP, ABS, and HDPE flexure hinges at different recycle ratios.

Table 5. Displacement equations of the PP, ABS, and HDPE plastics flexure hinge at different recycle ratios.

Recycle Ratio	PP	ABS	HDPE
25%	$y_1 = 5.728x_1$	$y_7 = 8.249x_7$	$y_{13} = 5.668x_{13}$
20%	$y_2 = 5.50x_2$	$y_8 = 7.843x_8$	$y_{14}= 5.404x_{14}$
15%	$y_3 = 5.381x_3$	$y_9 = 7.646x_9$	$y_{15} = 5.159x_{15}$
10%	$y_4 = 5.288x_4$	$y_{10} = 7.506x_{10}$	$y_{16} = 4.852x_{16}$
5%	$y_5 = 5.183x_5$	$y_{11} = 7.233x_{11}$	$y_{17} = 4.616x_{17}$
0%	$y_6 = 5.036x_6$	$y_{12} = 7.152x_{12}$	$y_{18} = 4.436x_{18}$
Average ratio	5.35	7.60	5.02

Figure 6 shows the comparison of the amplification ratio among the PP, ABS, and HDPE flexure hinges at different recycle ratios. The pure PP, ABS, and HDPE flexure hinges achieve the highest amplification ratios of 5.728, 8.249, and 5.668. The average amplification ratio values of all recycle ratios are 5.35, 7.60, and 5.02 corresponding to the PP, ABS, and HDPE flexure hinges. Generally, the ABS flexure hinge has the highest amplification ratios, followed by the PP flexure hinge. HDPE flexure hinge has the lowest highest amplification ratios among these plastic types. The reason is for this is the order's gradual reduction in the tensile strength and elastic modulus of the PP, ABS, and HDPE plastics. Moreover, the highest amplification ratio is 8.249, gained by the ABS flexure hinge in the packing pressure case. In reverse, the HDPE flexure hinge in the cooling time case has the lowest amplification ratio of 4.436.

Table 6 presents the amplification ratios of some common flexure hinge materials to compare the amplification ratio of these plastic hinges with other materials. The aluminum alloys and spring steel could produce a flexure hinge with a greater amplification ratio compared to the PP, ABS, and HDPE flexure hinges due to the stronger mechanical properties [31,32]. The amplification ratios of the PP, ABS, and HDPE flexure hinges are compatible with smart memory alloys and titanium alloys [33,34].

Table 6. Amplification ratios of different flexure hinge materials.

Materials	Amplification Ratio	References
PP	5.35	This report
ABS	7.6	This report
HDPE	5.02	This report
Aluminum alloys	41	Chen et al. [31]
Spring steel	13–15	Ling et al. [32]
Titanium alloys	6.0	Fiaz et al. [33]
Smart memory alloys	2.2	Maffiodo et al. [34]

In general, the HDPE flexure hinge has the lowest amplification ratio compared to the ABS and PP flexure hinges. It is interesting to note that these plastic hinges have amplification ratios that could be like those of titanium alloy hinges but lower than those of the spring steel and aluminum alloy hinges. More research could explore the effects of the hinge shape on the performance of the injected plastic flexure hinge.

3.3. LDPE/TPU Blend Flexure Hinge

In the previous section, the flexure hinges were produced with PP, ABS, and HDPE plastics. The recycle ratios of the PP, ABS, and HDPE plastics were also investigated. This section further investigates the LDPE blend flexure hinge, combining it with 0–25%

TPU. As shown in Section 2, the LDPE polymer is weaker than all PP, ABS, and HDPE plastics. Therefore, adding the TPU could change the flexure hinges performance made from LDPE/TPU blend by enhancing the mechanical properties.

Figure 7 displays the average displacement diagrams of LDPE blend flexure hinge at different TPU percentages. With the maximum input value of 95 μm, the average output value is 947 μm, indicating the high amplification rate of the hinge. The regression equations for the average values of the input and output displacements are as follows:

$$y_{19} = 2.853x_{19} \tag{19}$$

$$y_{20} = 4.517x_{20} \tag{20}$$

$$y_{21} = 6.323x_{21} \tag{21}$$

$$y_{22} = 9.376x_{22} \tag{22}$$

$$y_{23} = 10.37x_{23} \tag{23}$$

$$y_{24} = 10.504x_{24} \tag{24}$$

where y_{19}, y_{20}, y_{21}, y_{22}, y_{23}, and y_{24} are the output data; and x_{19}, x_{20}, x_{21}, x_{22}, x_{23}, and x_{24} are the input data of the LDPE/TPU blend flexure hinge at TPU percentages of 0%, 5%, 10%, 15%, 20%, and 25%.

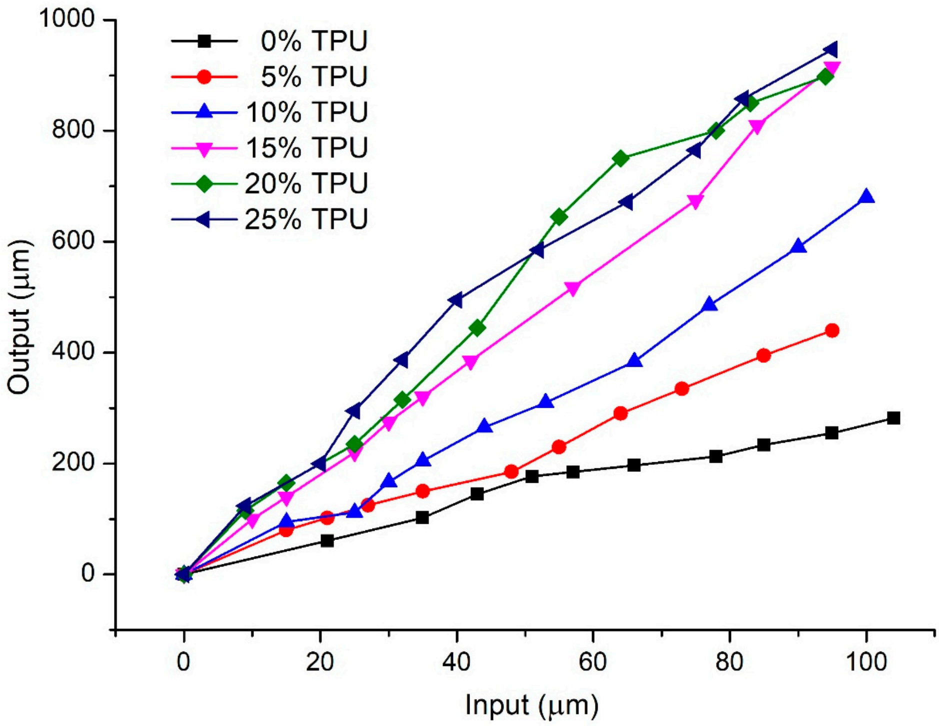

Figure 7. Average displacement diagrams of LDPE blend flexure hinge at different TPU percentages.

Improving the input value mostly leads to a linear increase in the output value. The amplification ratio values are 2.85, 4.517, 6.323, 9.376, 10.37, and 10.504, corresponding to the LDPE/TPU blend flexure hinge at 0%, 5%, 10%, 15%, 20%, and 25% TPU percentages. Generally, adding more TPU to the LDPE/TPU blend gives rise to the amplification ratio. The pure LDPE flexure hinge has the lowest amplification ratio of 2.85, while the 25% TPU blend has the highest amplification ratio of 10.504. From 0 to 15%, increasing the TPU percentage leads to a strong improvement in the amplification ratio. Adding 15% TPU results in the highest improvement rate compared to other cases. Specifically, from 15% to 25%, the amplification ratio only experiences a slight improvement from 9.376 to 10.504. The reason could be the good compatibility of the TPU with the LDPE polymer when adding 5–15%, as mentioned in the following figure. Adding more than 15% TPU leads to a lower efficiency as the LDPE/TPU blend is saturated. The average amplification ratio values of PP, ABS, and HDPE flexure hinges are 5.35, 7.60, and 5.02, respectively. Compared to the PP, ABS, and HDPE flexure hinge, the LDPE/TPU blend hinge has a wider range of amplification ratio of 2.85–10.504. Notably, modifying the blend percentage causes a greatly higher change rate in the amplification ratio than changing the recycle ratio. This result is consistent with the study by Thomas et al. [35], which indicated that if the TPU percentage is less than 80%, blending TPU into LDPE could result in a better tensile strength due to the good compatibility between them. The improvement in the tensile strength could lead to a better amplification ratio of the LDPE/TPU blend.

Figure 8 shows the SEM microstructure of different plastic flexure hinges. Figure 8a–c shows a smooth surface, indicating the homogeneous structure of ABS, PP, and HDPE plastics. Notably, Figure 8d shows a heterogeneous microstructure, with some particles presenting the TPU phase in the LDPE matrix, pointing out the good compatibility of the TPU with the LDPE polymer. The presence of the TPU phase helps improve the mechanical properties of the LDPE/TPU blends, leading to a higher amplification ratio.

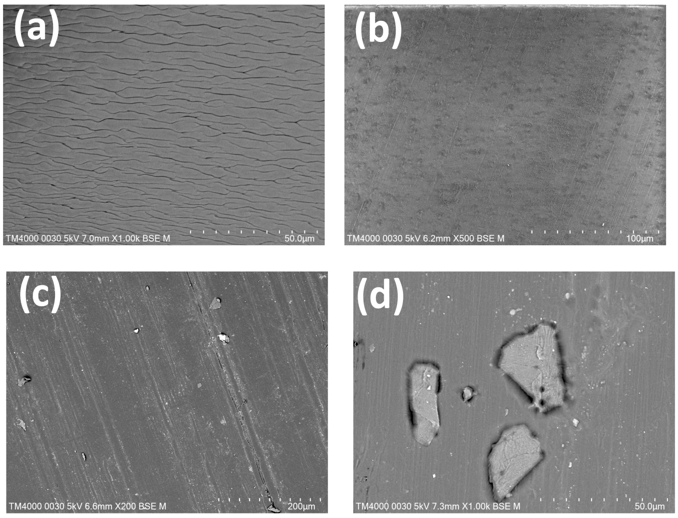

Figure 8. SEM microstructure of the plastic flexure hinges: (**a**) ABS, (**b**) PP, (**c**) HDPE, and (**d**) LDPE/TPU.

4. Conclusions

This study focuses on making plastic flexure hinges out of various plastics such as ABS, PP, HDPE, and LDPE/TPU blend. The recycle ratios are also examined to improve the hinge efficiency. The amplification ratios of different recycle ratios and plastic types were measured and compared. Some interesting results that could be named are:

1. The input and output displacements of all PP, ABS, and HDPE hinges are in a linear relationship. The existence of recycled plastics has no effect on this principle. The pure PP, ABS, and HDPE flexure hinges achieve the highest amplification ratios of 5.728, 8.249, and 5.668. The amplification ratio is lowered by the addition of recycled plastics. However, this amplification ratio reduction is not very high. In comparison to pure plastic hinges, the 25% recycling ratio PP, ABS, and HDPE flexure hinges obtain an amplification ratio that is 12%, 13.3, and 21.7% lower. Furthermore, the use of recycled plastics could reduce the requirement for new plastic created from raw resources.
2. With the PP flexure hinge, a maximum input value of 157 μm could lead to an output value of 886 μm. However, the ABS flexure hinge could gain an output value of

833 μm at a maximum input value of 115 μm. Finally, with the HDPE flexure hinge, a maximum input value of 175 μm could lead to an output value of 857 μm. For the PP, ABS, and HDPE flexure hinges, respectively, the average amplification ratio values of all recycling ratios are 5.35, 7.60, and 5.02. In terms of amplification ratios, the ABS flexure hinge is often better than the PP and HDPE flexure hinge. The HDPE flexure hinges have the lowest amplification ratio among these plastic types.

3. The amplification ratio typically develops as more TPU is added to the LDPE/TPU blend. The TPU's strong compatibility with the LDPE polymer may be the reason for this. The LDPE/TPU blend hinge offers a broader range of amplification ratio of 2.85–10.504 than the PP, ABS, and HDPE flexure hinges. It is noteworthy that altering the blend percentage has a much greater impact on the amplification ratio than adjusting the recycling ratio. By identifying the best plastic kinds, the findings expand the range of uses for plastic flexure hinges. Besides finding suitable plastics, further investigations could survey the effects of the hinge shape, the hinge dimension, and the hinge design on its performance. The temperature condition, humidity, and degradation could also impact the plastic flexural hinge and need further investigation.

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