Jurnal Rekayasa Mesin
p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol. 18, No. 2, Agustus **2023**, hal. 241-252

The Characterization of Mechanical and Chemical Properties of Recycled Styrofoam Waste Employing Extrusion Process

Budi Triyono, Destri Muliastri, Devi Eka Septiyani A*
Department of Mechanical Engineering, Politeknik Negeri Bandung
Gegerkalong Hilir Street, Ciwaruga, Parongpong, Bandung, West Java 40559, Indonesia

*E-mail: devi.eka@polban.ac.id

Diajukan: 23-06-2023; Diterima: 01-08-2023; Diterbitkan: 21-08-2023

Abstrak

Limbah styrofoam merupakah limbah berbahan dasar plastik berjenis polistirena berbentuk busa dengan densitas yang rendah. Para pemulung atau pendaur ulang tidak tertarik untuk menerima limbah styrofoam karena densitas yang ringan sehingga tidak efektif dalam transportasi dan penyimpanan. Limbah styrofoam sebenarnya telah dapat dikonversi menjadi produk polistirena padat melalui proses termal-ekstrusi namun belum tersedia data terkait temperatur operasi optimum dan karakteristik dari produk polistirena padat yang dihasilkan. Tujuan dari penelitian ini adalah menganalisis sifat produk polistirena padat hasil daur ulang limbah styrofoam dan menentukan temperatur optimum dari proses pengolahan termal-ekstrusi untuk dibandingkan dengan karakteristik polistirena original berdasarkan hasil uji tarik dan uji impak. Pada penelitian ini, proses pengolahan dilakukan dengan metode termal-ekstrusi, dimana styrofoam dilelehkan dan ditekan kedalam cetakan untuk menghasilkan padatan polistirena. Penelitian dilakukan dengan variasi temperatur ekstrusi pada 180°C, 200°C, dan 220°C. Padatan polistirena selanjutnya dicetak membentuk spesimen uji tarik dan uji impak dengan metode *injection molding*. Hasil penelitian menunjukkan bahwa temperatur ekstrusi optimal adalah pada 200°C dengan nilai kekuatan tarik dan impak berturut-turut sebesar 27,55 MPa dan 1.069 j/m^2. Dibandingkan dengan polistirena original, nilai kekuatan tarik lebih rendah 25,3% dan nilai kekuatan impak lebih rendah 29,5%. Penurunan nilai kekuatan tarik dan impak disebabkan karena ikatan molekul pada polistirena daur ulang mengalami pemendekan selama proses pengolahan termal-ekstrusi. Walaupun kekuatan tarik dan impak masih lebih rendah, pemanfaatan sampah styrofoam dengan metode termal-ekstrusi mempunyai potensi untuk dikembangkan ketahap produksi dan komersialisasi karena produk yang dihasilkan jadi memiliki nilai ekonomi yang baik dan juga dapat mengurangi penggunaan polistirena original dan sekaligus dapat menyelesaikan permasalahan sampah styrofoam.

Kata kunci: ekstrusi; limbah styrofoam; polistirena; uji tarik; uji impak

Abstract

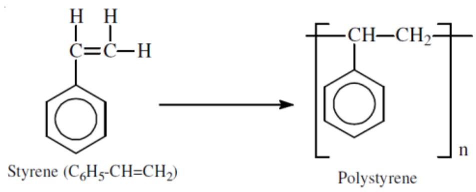
Styrofoam waste is a polystyrene plastic-based waste in the form of foam with low density. Scavengers or recyclers are not interested in receiving styrofoam waste because of its light density which makes it ineffective in transportation and storage. Styrofoam waste can actually be converted into solid polystyrene products through a thermal-extrusion process but data regarding the optimum operating temperature and the characteristics of the resulting solid polystyrene products are not yet available. The purpose of this study was to investigate the properties of solid polystyrene products resulting from recycled styrofoam waste and determine the optimum temperature of the thermal-extrusion treatment process to be compared with the characteristics of the original polystyrene based on the results of tensile and impact tests. In this study, the processing was carried out using the thermal-extrusion method; Styrofoam is melted and extruded into a mold to produce polystyrene solids. The research was carried out with variations in extrusion temperature at 180°C, 200°C, and 220°C. The polystyrene solids are then molded into tensile and impact test specimens by injection molding. The results showed that the optimal extrusion temperature was 200°C with tensile and impact strength values of 27.55 MPa and 1,069 j/m2, respectively. Compared to the original polystyrene, the tensile strength value is 25.3% lower and the impact strength value is 29.5% lower. The decrease in the tensile and impact strength values is due to the shortening of the molecular bonds in the recycled polystyrene during the thermal-extrusion treatment process. Even though the tensile strength and impact are still lower, the use of styrofoam waste using the thermal-extrusion method has the potential to be developed at the production and commercialization stage because the resulting product has good economic value and can also reduce the use of original polystyrene and at the same time can solve the problem of styrofoam waste.

Keywords: *extrusion; styrofoam waste; polystyrene; tensile test; impact test*

1. Introduction

In recent years, plastic materials are used for many purposes. Even though, plastic pollution is one of the big problems in the world. Plastic pollution can afflict both lands and oceans [1][2], which is plastic hard to be recycled [3]. During the last decade, Polystyrene (PS) contribute around 10 wt.% of the plastic waste and its poor recycling rates were the greatest concern [4][5]. The first production of polystyrene as commercial plastic began around 1930. Polystyrene product are widely used in our daily lives as single use of cup and packaging food, disposable cutlery, electronics, building materials, CD and DVD cases, smoke detector housings and automotif parts [6,7], [8]. Because of its good endurance and lower production cost, polystyrene is very popular and good alternative. In the US, 68 billion lbs of polystyrene have been produce every year and around 1 billion lbs used as single use product [8].

Polystyrene also known as poly (1-phenylethene-1, 2-diyl) or thermocole is an aromatic polymer made from the monomer, known as styrene [9].



Polystyrene is thermoplastic polymer, brittle and its kind of amorphous polymer. The physical properties is transparent and has higher refraction indeks, good thermal conductivity, the glass transition at 100°C and melting point at 240°C.

There are two kinds of polystyrene. First is extruded polystyrene (XPS). The applications is in containers likes coffee cups and food trays. Second is expanded polystyrene (EPS). It has the trade name styrofoam. It is a thermoplastic polymer, light material but great volume, typically of white color with close pores [10] and is one of the most widely used as packaging tools and insulating materials [11]. The great volume of EPS is because of the processing technology. A blowing agent, pentane or butane, is addes during the polymerization process. This agent is heated together with the polymer and its volume increase rapidly [3]. Based on the fact that the physical properties of XPS foam has higher density and compressive strength that EPS [12]. Most polystyrene are used as foam products.

Styrofoam is a single-use product, which means it is nonbiodegradable material and will continue to pollute our environment. Styrofoam is composed of about 5% polystyrene (PS) and 95% air [13]. The polymerization process of Styrofoam is condensation process and original polystyrene is adition polymerization.

The increasing of styrofoam waste is not along with an increase in the management of recycled styrofoam process. Fitidarini and Damanhuri [14] investigated the performers of styrofoam waste management activities of in the city of Bandung. Most people just throw away the styrofoam and is disposed as a waste. The total estimation of styrofoam waste from all of landfills in Bandung city is 21,769 tons/month and only 5,184 tons of styrofoam waste had been recycled by waste collector and the rest waste is burned. Burning styrofoam waste produces harmful gases such as styrene, hydrochlorofluorocarbon (HCFC), carbon black, carbon monoxide and polycyclic aromatic hydrocarbons (PAHs) [15].

Styrofoam is a type of plastic that is difficult to decompose by microorganisms. Styrofoam has a relatively low density of 28-40 kg/m^3 and has a big volume, so it takes up a lot of space [16]. It causes styrofoam waste lose of interest by the waste collector. The waste collectors prevent receiving the waste in one piece to distribute to the manufacturer's recycled product which increase the cost of transporting the sytrofoam waste from waste generating source to recovery plant. One of the effective approaches to remarkably reduce styrofoam wastes is recycling them [1]. Noguchi et al [17] explained that the recycled styrofoam has three kinds of method. The first is material recycling, which is reducing styrofoam in volume by heating process, and then it melts because of temperature, and styrofoam came out as a solid material or pellet. It can be reused into raw material and daily product. The second is chemical recycling, which is aimed to recovering the styrene monomer to reuse as chemical resource. The third is thermal recycling, by which combustion chamber furnace unit processing [15].

Samper et.al [3] studied recycling of expanded polystyrene from packaging. The processing is conducted on a two-roll mill at 110 oC. The results show that tensile test of recycled polystyrene and the original materials have similar value of mechanical behavior. Recycled Polystyrene can substitute the original polystyrene in some industrial processing, thus reducing the cost of the final product. Ali et.al [18] also investigated optimizing the application of extrusion technology to recycle styrofoam waste. Based on this research, the optimum heating temperature ranges from 110 – 120°C with a flow rate of 2.7 – 3.6 m/min. the resulting product is a solid material and have white colour. The similar research had been done by Aqil et.al [16], a styrofoam waste treatment machine with the extrusion method has been successfully built and operated. Variables in the operation of this machine are at temperature of 180, 200 and 220 oC with the speed operation is 130 rpm. The reverse engineering process show the density of recycled styrofoam was increased 60 times higher than the density of initial styrofoam waste before recycled.

Most of the studies as mentioned above have shown that the reheat process method has been proven to produce polystyrene solid products. The main problem is styrofoam has a big volume and low density as mention above. In previous researches, the focus was on reducing waste volume and reducing storage and transportation costs. However, there is no data regarding the properties of recycled styrofoam yet. In this study, the thermal-extrusion process will be develop to recycle the styrofoam waste. The main objective of this research is to obtain data on the properties of recycled styrofoam materials and find the optimum temperature that can produce recycled styrofoam with optimal properties compared to the original polystyrene properties by testing the tensile strength and impact strength.

2. Material and methodology

Styrofoam from plastic wastes especially for packaging and bouquet board are one of the most consumed. As a result, greater number of used Styrofoam has become an emerging problem of contaminated nature. To eliminate styrofoam waste, the research program involves the production of recycled styrofoam as a solid material by investigating the mechanical and chemical properties of recycled styrofoam solid material (SRS).

1.1. Material

The Styrofoam used in this study is expanded polystyrene (EPS). EPS foam or styrofoam waste is obtained from a flower bouquet shop in Bandung, Indonesia. A white colour of styrofoam were used for the experiment.

1.2. Production of SRS

The manufacturing process of solid material of recycled styrofoam (SRS) is summarized in Fig. 1. Before being provided to the extrusion machine, the styrofoam was chopped into small sizes then processed using an extrusion machine. Extrusion is the process of thermoplastic polymers beyond its melting temperature (T_m) and forcing it to flow through the band heater [19]. Figure 1 shows the process of recycling styrofoam waste using an extrusion process that converts low density styrofoam waste into solid polystyrene. A solid polystyrene has much higher density than styrofoam waste. This solid product will be further investigated. In this research, the experiment was more focused on investigating the effect of temperature on the mechanical properties of solid recycled styrofoam. The variations in temperature are 180, 200, and 220°C based on the previous research [16]. The output of this product is a solid material of recycled styrofoam illustrated by the Figure 2.

p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol.18|No.2|241-252|Agustus|2023

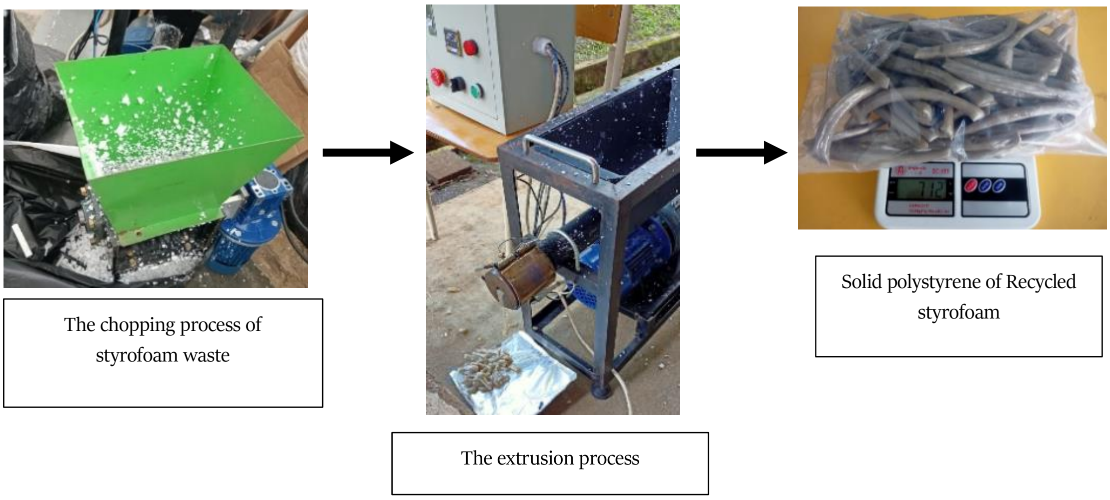


Figure 1. The overview of the extrusion process

Based on the Figure 2, a solid material of recycled styrofoam is gradually dark when the temperature increased. It is because of the heating process of styrofoam waste. At higher temperature of 220°C, the material darkest than another, because of the temperature is verge on the melting temperature of styrofoam at 240°C.

Figure 2. Solid material of recycled Styrofoam at various temperature of extrusion process

2.3 Specimens and Analysis Method

To investigate the strength of solid material of recycled styrofoam (SRS), the tensile and impact strength, a standard specimen test were prepared. The objective of the tensile test and impact test are to know the strength of recycled styrofoam compared to original polystyrene. The tensile and impact test spesimens were pepared using injection molding process.

Tensile test were performed at room temperature (27°C) and followed ASTM D638 standard methods. Figure 3 show the tensile test specimens. Tensile test was carried out using a Zwick Roell machine type Z020 with a tensile speed of 5 mm/min.

Figure 3. Specimen of tensile test: (a) original polystyrene (PS), (b) SRS at 180°C, (c) SRS at 200°C, (d) SRS at 200°C

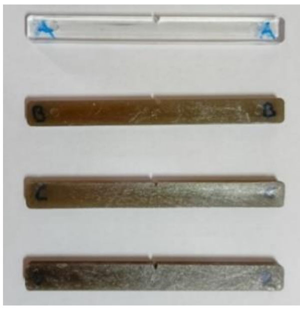


Figure 4. Specimen of impact test: (a) original polystyrene (PS), (b) SRS at 180°C (c) SRS at 200°C (d) SRS at 200°C

The standard test of impact test is ASTM D6110 using the Charpy method. Figure 4 show the impact test specimens with "V" notch. The Fourier Transform Infra-Red (FTIR) was performed on the various temperature of SRS and original polystyrene (PS) to determination of function group on the chemical compound. X-Ray Diffraction (XRD) was also conducted to identify the composition of SRS.

3. Results and Discussion

This section provides details for chemical and mechanical properties of Styrofoam waste. There are two test which had been done in this research: tensile test and impact test.

1.3. Effect of Solid Material of Recycled Styrofoam on Mechanical Properties

The aim of tensile test is to determine the tensile strength, strain value, and modulus elasticity of recycled styrofoam (SRS) and original Polystyrene. The test was repeated 3 times for each variation of the specimen test. As depicted in Figure 5, Figure 6, and Figure 7, the tensile stress-strain relationship of original polystyrene and SRS at various temperature exhibited higher stress value and followed by SRS at T = 200°C. The curve shows that the material has brittle properties, where higher stress value and lower strain value. Tensile test results can be seen in the Table 1.

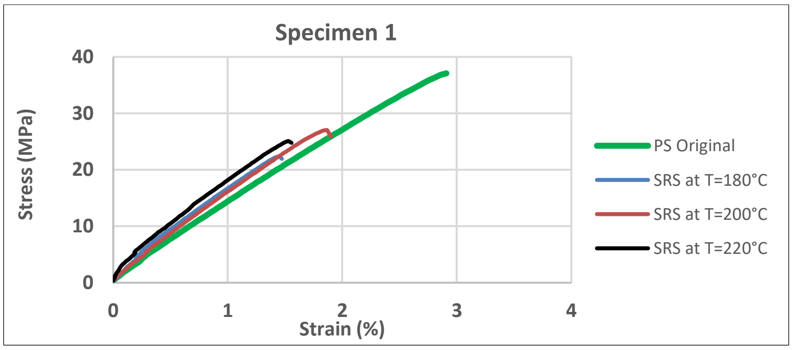


Figure 5. Stress-Strain relationships of polystyrene original and SRS at various temperature for batch 1 specimens

Figure 6. Stress-Strain relationships of polystyrene original and SRS at various temperature for batch 2 specimens

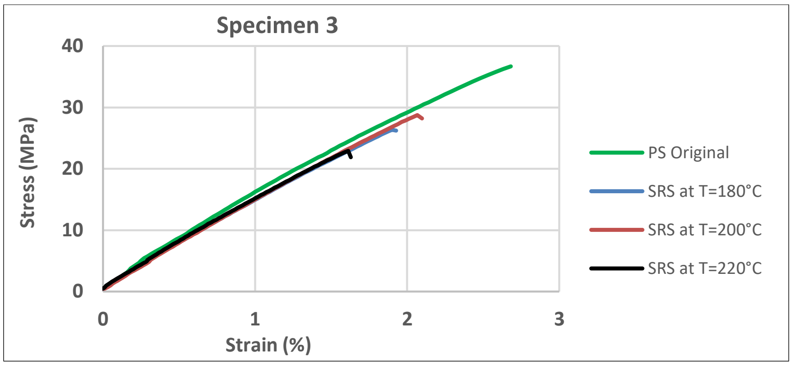


Figure 7. Stress-Strain relationships of polystyrene original and SRS at various temperature for batch 3 specimens

Table 1 shows the average tensile strength of each variation specimen. The highest tensile strength is the original polystyrene at 36.88 MPa and the tensile strength closest to the original polystyrene is recycled styrofoam processed at a 200°C extrusion temperature of 27.55 MPa.

Table **2** shows the average strain value of each variation specimen. The highest strain value is the original polystyrene at 2.79% and the strain value closest to the original polystyrene is recycled styrofoam processed at a 200°C extrusion temperature of 1.95%. Table 3 shows modulus elasticity data. The highest modulus elasticity is recycled styrofoam at temperature of 220°C because of heating temperature is also the highest. It cause the polymer to stretch due to the given temperature.

The purpose of impact test is to determine the toughness of original polystyrene and recycled polystyrenes. Impact test was carried out using a Zwick Roell machine type with theoretical impact speed of 2.9 m/s.

Table **4** shows that the impact strength of the original Polystyrene is 1,517.21 j/m^2. The impact strength value which is close to the original polystyrene is recycled styrofoam at 200°C extrusion temperature of 1,069.00 j/m^2.

Table 1. Tensile strength of Original Polystyrene and the variations of recycled Styrofoam

Specimen	Tensile Strength of Original PS (MPa)	Tensile Strength of recycled Styrofoam T = 180°C (MPa)	Tensile Strength of recycled Styrofoam T = 200°C (MPa)	Tensile Strength of recycled Styrofoam T = 220°C (MPa)
Specimen 1	37.19	22.45	27.04	25.14
Specimen 2	36.78	26.86	26.63	22.53
Specimen 3	36.68	26.51	28.99	23.04
Average	36.88	25.27	27.55	23.57
Deviation Standart	0.27	2.45	1.26	1.39

Table 2. Strain of Original Polystyrene and the variations of recycled Styrofoam

Specimen	Strain of Original PS (MPa)	Strain of recycled Styrofoam T = 180°C (%)	Strain of recycled Styrofoam T = 200°C (%)	Strain of recycled Styrofoam T = 220°C (%)
Specimen 1	2.90	1.46	1.86	1.55
Specimen 2	2.81	1.94	1.91	1.50
Specimen 3	2.68	1.92	2.09	1.62
Average	2.79	1.77	1.95	1.56
Deviation Standart	0.1110	0.27	0.12	0.06

Table 3. Modulus Elasticity of Original Polystyrene and the variations of recycled Styrofoam

Specimen	Modulus Elasticity of Original PS (MPa)	Modulus Elasticity of recycled Styrofoam T = 180ºC (MPa)	Modulus Elasticity of recycled Styrofoam T = 200ºC (MPa)	Modulus Elasticity of recycled Styrofoam T = 220ºC (MPa)
Specimen 1	12.81	15.33	14.53	16.19
Specimen 2	13.06	13.82	13.89	14.94
Specimen 3	13.68	13.79	13.85	14.15
Average	13.18	14.32	14.09	15.10
Deviation Standart	0.44	0.88	0.37	1.02

Table 4. Impact Strength of Original Polystyrene and the variations of recycled Styrofoam

Specimen	Impact Strength of Original PS (MPa)	Impact Strength of recycled Styrofoam T = 180ºC (j/m^2)	Impact Strength of recycled Styrofoam T = 200ºC (j/m^2)	Impact Strength of recycled Styrofoam T = 220ºC (j/m^2)
Specimen 1	1445.01	873.76	1285.88	853.09
Specimen 2	1535.27	880.24	1049.18	872.15
Specimen 3	1571.37	780.61	871.95	880.33
Average	1517.21	844.87	1069.00	868.52
Deviation Standart	65.08	55.74	207.67	13.97

1.4. Effect of Solid Material of Recycled Styrofoam on Chemical Properties

FTIR testing was carried out to find out information related to chemical and physical structure, hydrogen bonding, degradation reactions and end group detection [20] in the original polystyrene polymers and solid material of recycled Styrofoam (SRS). The results of the FTIR test can be seen in Figure 8 and

Table **5** which show the test results of FTIR of original polystyrene, raw styrofoam before recycled, and SRS processed at temperatures of 180, 200, and 220°C.

The results of the FTIR analysis between original polystyrene and SRS results at temperatures of 180°C, 200°C, and 200°C have similar functional groups. As seen in the wave number 3448.72 cm^{-1} each test sample is at the peak of the wave number and functional group –OH. The wave number 2992 cm^{-1} is the functional group of hydrocarbons, namely –CH [21]. The same absorption peak is present in each of the test samples, which is narrowed and sharply downwards, meaning that the absorption at the wave number 2992 cm^{-1} is small. At peak wave numbers 1658 cm^{-1} and 1741cm^{-1} all test samples had the same wave absorption, which is sharp downwards and narrower, this indicates the presence of an aromatic functional group with carbonyl group C=O [22].

The Absorption Area with a Wave Number of 1083 cm^{-1} and an area of 1068 cm^{-1} is the fingerprint area, where the fingerprint area in the wave number is below 1500 cm^{-1}, in the fingerprint area of the functional group in all test samples, namely the single bond C-O. The difference in absorption that is wide and slightly sharp to the bottom is in the original Polystyrene and Styrofoam materials recycled at a wave number of 1083 cm^{-1}, because the energy absorbed and the vibration that occurs are very large, so the peak will widen.

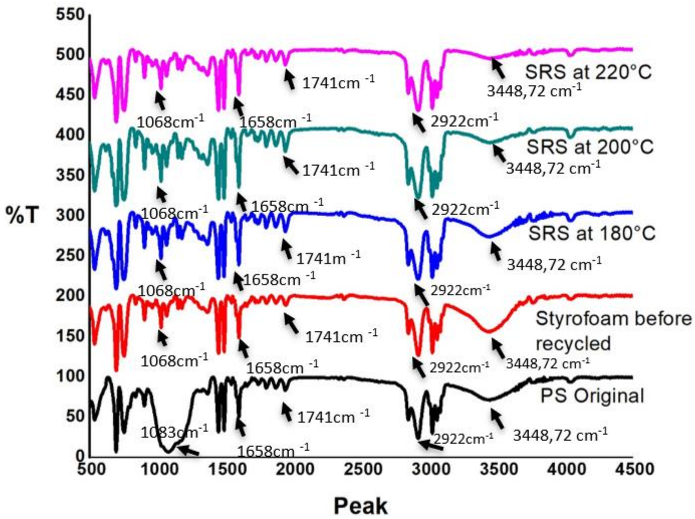


Figure 8. The Comparison of FTIR spectrum between original polystyrene and recycled polystyrene

Table 5. Functional Groups of Samples

Sample	Wave Number (cm^{-1})	Functional Groups
Polystyrene Original	3448.72 cm^{-1}	O-H
	2992 cm^{-1}	C-H
	1600-1800 cm^{-1}	C=O
	1083-1068 cm^{-1}	C-O
***Styrofoam* Before Recycled**	3448.72 cm^{-1}	O-H
	2992 cm^{-1}	C-H
	1600-1800 cm^{-1}	C=O
	1083-1068 cm^{-1}	C-O
***Recycled Styrofoam at* Temperature 180°C**	3448.72 cm^{-1}	O-H
	2992 cm^{-1}	C-H
	1600-1800 cm^{-1}	C=O
	1083-1068 cm^{-1}	C-O
***Recycled Styrofoam at* Temperature 200°C**	3448.72 cm^{-1}	O-H
	2992 cm^{-1}	C-H
	1600-1800 cm^{-1}	C=O
	1083-1068 cm^{-1}	C-O
***Recycled Styrofoam at* Temperature 220°C**	3448.72 cm^{-1}	O-H
	2992 cm^{-1}	C-H
	1600-1800 cm^{-1}	C=O
	1083-1068 cm^{-1}	C-O

Figure 9 shows the XRD spectrum each ordered domain, with the same inter-planar distance, gives a narrow diffraction peak. But in polymeric materials, these domains are characterized by very different inter-planar distances, giving diffraction peaks at different angles [23]. The comparison of XRD results between original polystyrene and SRS at 180, 200, 220 °C can be observed in Figure 9. PS Original was at the peak of 2θ = 8.96° with a small intensity, increasing intensity, and widening peak. seen at 2θ= 19.2°. The XRD results on Recycled Styrofoam at 180°C were at a high peak and widened at 2θ = 9.94°, and 18.9° with a planar spacing of 8.8, and 4.68, respectively. With Temperatures of 200°C and 220°C, it can be observed that there are 2 peaks with high intensity and almost the same distance between planars.

Differences in peaks on original polystyrene and SRS with variations in temperature can be influenced by external factors UV, X, gamma irradiation, and heating temperature. The temperature will affect the crystal structure of the polymer and the movement of the molecules [24]. The higher the temperature the movement of the molecules will widen so that the polymer is amorphous.

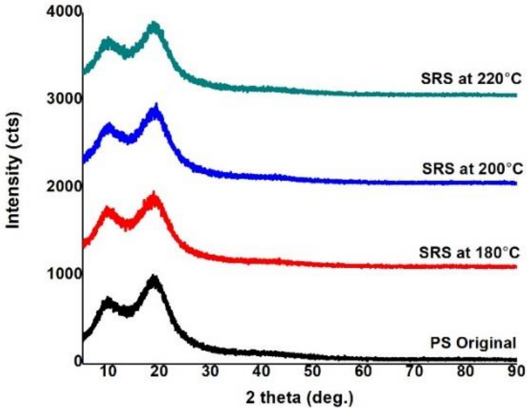


Figure 9. XRD patterns of original polystyrene and recycled styrofoam at various temperature

1.5. Discussion

Tensile strength is the maximum stress that a material can withstand when stretched before fracture. The tensile strength of the original polystyrene is higher than the recycled styrofoam, which is 36,883 MPa. The value of the tensile strength of recycled SRS at a temperature of 180°C is 25.27 MPa, 200°C is 27.55 MPa, and 220°C is 23.57 MPa, as shown in Figure 10.

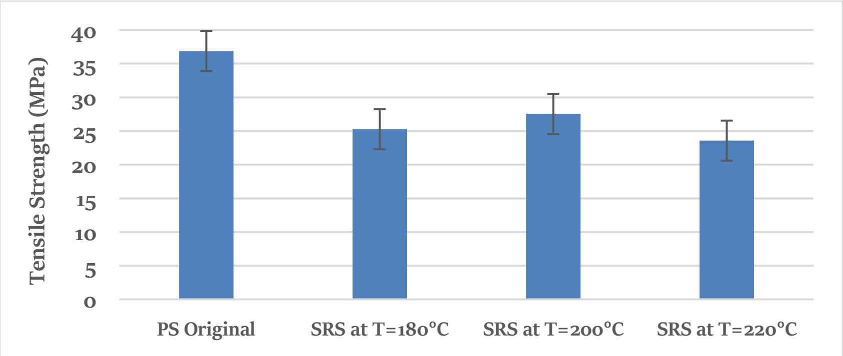


Figure 10. The comparison graph of tensile strength of original polystyrene and the recycled SRS

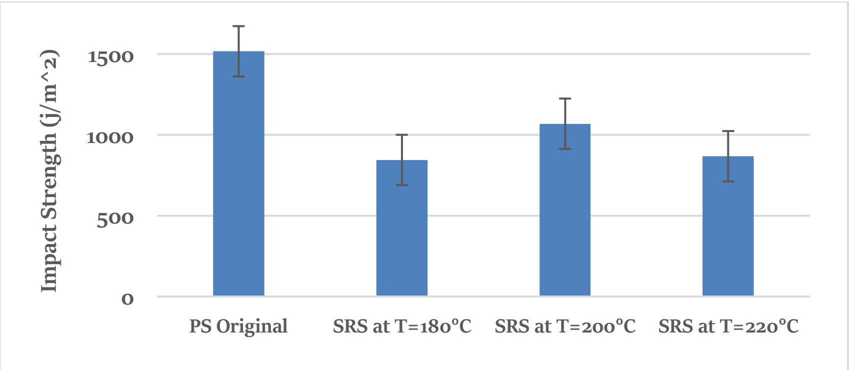


Figure 11. The comparison graph of impact strength of original polystyrene and the recycled SRS.

Figure 11 shows the effect of extrusion temperature on the impact strength. The impact strength of SRS at temperatures of 180, 200, and 220°C are 844.87 j/m^2, 1,069.00 j/m^2 and 868.52 j/m^2. The impact strength at temperature of 200°C is the highest one but it still lower than the impact strength of original polystyrene (1,517.22 j/m^2). The effect of temperature variation on the recycled properties of styrofoam is related to the glass temperature (T_g) and melting temperature (T_m). Polystyrena has a value of T_g = 100^{0}C and Tm = 240°C. When polystyrene is cooled below T_g, the polymer becomes brittle (glassy state), but when heated above T_g, polystyrene is softens. The polystyrene decomposed at 270^{o}C [24]. So that when the extrusion process at temperature of 180, 200, and 220°C are in the rubbery state or elastic state, where the molecular bonds are stretched. On the other hand, after the heating and cooling process, the recycled Styrofoam will become brittle. This occurs in polymers that are amorphous, where polystyrene is a type of amorphous polymer.

At the extrusion process temperature of 180°C, the heating that occurs in styrofoam is not optimal and the styrofoam has not melted completely, whereas when the temperature of extrusion process is at 200°C, the styrofoam waste treatment process occurs optimally. At the extrusion process temperature of 220°C, the styrofoam heating is overheating where the temperature is close to the melting point of the original polystyrene, so that the value obtained in tensile and impact test was decreased. The tensile and impact strength of recycled styrofoam are lower than original polystyrene. It is because of the temperature of the extrusion process. The chain bond of hydrocarbon will be shorten. The shortening of the molecular bonds in the recycled styrofoam causes its tensile strength decrease. It is due to the movement of the molecules and the distribution molecules. The distribution of the molecule will affect the mechanical properties. The wider distribution of molecules will cause the tensile strength and modulus elasticity decrease.

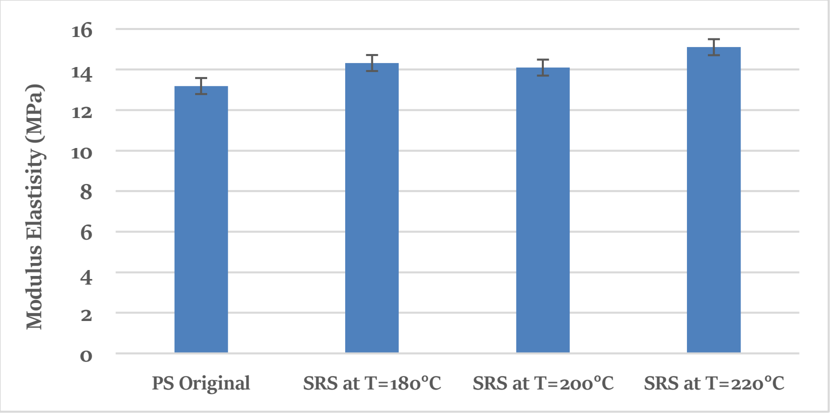


Figure 12. The comparison graph of the original polystyrene modulus elasticity with recycled Styrofoam

Modulus elasticity of the polymer is also important things. Modulus elasticity of recycled Styrofoam was increased with the increase of temperature, as shown in the Figure 12. The recycled styrofoam undergo repeated heating process, then the molecular bond stretch and the elongation was increased with the increase of temperature of extrusion process. The temperature of 220°C is close to the melting point of polystyrene original which is cause the molecular bond to stretch more than at a temperature of 180°C. The polymer material becomes softer due to the higher temperature.

4. Conclusion

The tensile and impact strength of original polystyrene is higher than solid material of recycled styrofoam (SRS) for all various temperature. The tensile strength of SRS at T = 180, 200, and 220°C are 25.27 MPa, 27.55 MPa, and 23.57 MPa. The tensile strength of T = 200°C is the highest one but it still lower than the tensile strength of original polystyrene (36.88 MPa). The impact strength of SRS at T = 180, 200, and 220°C are 844.87 j/m^2, 1,069.00 j/m^2 and 868.52 j/m^2. The impact strength of T = 200°C is the highest one but it still lower than the impact strength of original polystyrene (1,517.22 j/m^2). The optimum extrusion temperature is at a temperature of 200°C but the tensile strength of the recycled styrofoam polystyrene material is still 25.3% lower than the original polystyrene. In addition, the impact strength is also lower by about 29.5%. The decrease in tensile and impact strength is due to the molecular bonds in the recycled polystyrene being shortened during the recycling process (thermal-extrusion process). The mechanical properties of recycled styrofoam waste polystyrenes are still below the original polystyrene, but the utilization of styrofoam waste with the extrusion method has the potential to be continued to the production or commercial stage because the resulting product has good economic value, can reduce styrofoam waste, and reduce the use of original polystyrene derived from non-renewable fossil fuels.

Acknowledgements
This research was funded by Pusat Penelitian dan Pengabdian kepada Masyarakat (P3M), Politeknik Negeri Bandung, in the scheme of Applied Research Program in 2022.

References
[1] Jirawattanasomkul T, Likitlersuang S, Wuttiwannasak N, Varabuntoonvit V, Yodsudjai W, Ueda T. Fibre-reinforced polymer made from plastic straw for concrete confinement: An alternative method of managing plastic waste from the COVID-19 pandemic. Eng J. 2021;25(3):1–14.
[2] Tukker A, Barbarossa V. Resources , Conservation & Recycling Recycled plastic packaging from the Dutch food sector pollutes Asian oceans. 2022;185(July).
[3] Samper MD, Garcia-Sanoguera D, Parres F, López J. Recycling of expanded polystyrene from packaging. Prog Rubber, Plast Recycl Technol. 2010;26(2):83–92.
[4] Hidalgo-Crespo J, Moreira CM, Jervis FX, Soto M, Amaya JL, Banguera L. Circular economy of expanded polystyrene container production: Environmental benefits of household waste recycling considering renewable energies. Energy Reports [Internet]. 2022;8:306–11. Available from: https://doi.org/10.1016/j.egyr.2022.01.071
[5] Almusawi A, Lachat R, Atcholi KE, Bi STIÉ. Manufacturing and Characterisation of Thermoplastic Composite of Hemp Shives and recycled Expanded Polystyrene Manufacturing and Characterisation of Thermoplastic Composite of Hemp Shives and recycled Expanded Polystyrene. 2019;(July 2016):1–6.
[6] Ward CP, Armstrong CJ, Walsh AN, Jackson JH, Reddy CM. Sunlight Converts Polystyrene to Carbon Dioxide and Dissolved Organic Carbon. Environ Sci Technol Lett. 2019;6(11):669–74.
[7] Huang Z, Shanmugam M, Liu Z, Brookfield A, Bennett EL, Guan R, et al. Chemical Recycling of Polystyrene to Valuable Chemicals via Selective Acid-Catalyzed Aerobic Oxidation under Visible Light. J Am Chem Soc. 2022;144(14):6532–42.
[8] Susmanto P, Cundari L, Putri RW, Ibrahim O, Oktari D. Pengaruh waktu dan temperatur terhadap sifat fisik cairan hasil proses perengkahan limbah plastik jenis expanded polystyrene. :123–8.
[9] Donbebe W, Dikio ED. Comparative study of polystyrene and polymethylmethacrylate waste as adsorbents for sorption of Pb2+ from aqueous solution. 2014;(December 2016).
[10] Series C. Resistance to compression of conventional concrete alleviated through partial substitution of coarse aggregate for expanded polystyrene Resistance to compression of conventional concrete alleviated through partial substitution of coarse aggregate for expa. 2018;
[11] Science E. Progresses in Polystyrene Biodegradation and Prospects for Solutions to Plastic Waste Pollution Progresses in Polystyrene Biodegradation and Prospects for Solutions to Plastic Waste Pollution. 2018;
[12] Nukmal N, Umar S, Amanda SP, Kanedi M. Effect of Styrofoam Waste Feeds on the Growth , Development and Fecundity of Mealworms (Tenebrio molitor). 2018;24–8.
[13] Siyal AN, Memon SQ, Khuhawar MY. Recycling of styrofoam waste: Synthesis, characterization and application of

novel phenyl thiosemicarbazone surface. Polish J Chem Technol. 2012;14(4):11–8.

[14] Fitidarini NL, Damanhuri E. Timbulan Sampah Styrofoam di Kota Bandung. J Tek Lingkung. 2011;17(2):87–97.

[15] Fikri E, Veronica A. Efektivitas Penurunan Konsentrasi Karbon Monoksida (CO) dengan Sistem Kontak Media Karbon Aktif Menggunakan Variasi Ukuran Partikel Pada Proses Pembakaran Sampah Polistirena Foam. J Kesehat Lingkung Indones. 2018;17(1):32.

[16] Murtadho A, Triyono B, Eka D, Arifin S, Kunci K. Perancangan Alat Pengolah Sampah Expanded Polystyrene Foam (EPS) Portabel untuk Mengatasi Masalah Sampah di Sektor Rumah Tangga. Pros 12th Ind Res Work Natl Semin. 2021;12:388–93.

[17] Noguchi T, Miyashita M, Lnagaki Y, Watanabe H. A new recycling system for expanded polystyrene using a natural solvent. Part 1. A new recycling technique. Packag Technol Sci. 1998;11(1):19–27.

[18] Mahmudi A, Londa P. Optimasi Penerapan Teknologi Ekstrusi pada Prototipe Mesin Daur Ulang Limbah Styrofoam. Rotasi. 2017;19(2):92.

[19] Haile L. Study of Recycling of Waste High Impact Polystyrene (PS-HI) and Polystyrene with Flame Retardant Additives (PS-FR) Co-Polymers. J Text Sci Fash Technol. 2021;7(4):1–11.

[20] Umamaheswari S. FTIR analysis of bacterial mediated chemical changes in Polystyrene foam. 2016;(June).

[21] Tran ATK, Pham TT, Nguyen QH, Hoang NTT, Bui DT, Nguyen MT, et al. From waste disposal to valuable material: Sulfonating polystyrene waste for heavy metal removal. J Environ Chem Eng [Internet]. 2020;8(5):104302. Available from: https://doi.org/10.1016/j.jece.2020.104302

[22] Wu H Der, Wu SC, Wu I Der, Chang FC. Novel determination of the crystallinity of syndiotactic polystyrene using FTIR spectrum. Polymer (Guildf). 2001;42(10):4719–25.

[23] Niculăescu C, Olar L, Stefan R, Todica M, Pop CV. XRD and IR investigations of some commercial polystyrene samples thermally degraded. Stud Univ Babes-Bolyai Chem. 2018;63(2):63–70.

[24] Sattar MA, Najeeb M, Mahdi SH, Fadil NQ. The effect of heat treatment on the degree of crystallinity and grain size for (N6, PS) polymers. J Xi'an Univ Archit Technol [Internet]. 2020;12(3):4319–25. Available from: http://www.xajzkjdx.cn/gallery/388-mar2020.pdf