Volume 7, Issue 1, pp. 1-9, 2023.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Possibilities of Development of Composite Materials from Tetra Pak and Metalized Film-Based Packaging Waste for Non-Structural Applications

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Abstract— *Packaging protects the goods from environmental factors and delivers them in the best conditions to the consumer. Especially, Tetra Pak is widely used as an aseptic packaging in the food industry. Tetra Pak-based packaging waste is generated due to the massive use and throw and Metallised film-based packaging waste. These wastes can be recycled in various methods, according to previous studies. Most studies focus on producing composite materials that can replace the material needs for non-structural applications. Tetra Pak and Metallised films can improve the thermal and mechanical properties such as tensile strength, compressive strength, density, water resistance, screw holding, MOR, etc., as the required standard because of the high fibre content and Aluminium layer. Binding agents also can play a significant role in composite production. This article has outlined the possibility of manufacturing composite material from Tetra Pak and Metallised wastes as reinforcement materials to minimize the problems generated due to packaging waste.*

Keywords— *Tetra Pak, Metallised Film, Packaging waste, Composite material, Waste Recycling.*

I. INTRODUCTION

Waste generation is a vast problem in the world's population growth and industrialization. Food and energy demand are increased as a result of the population growth of the world [1]. As a result, the world's solid waste generation is growing rapidly day by day [2]. The world generates approximately 25 billion tons of waste annually, and 1.3 billion tons of municipal solid waste was generated in 2016. The municipal solid waste per person per day increases yearly and will exceed 1.42 Kg in 2025 [3]. Especially world food demand has risen as a result of population growth. Then, Both developed and developing countries faced recycling and environmental problem due to the rapid generation of food packaging waste from the beverage and dairy industries [4]. Food packaging waste largely contributes to increasing the solid waste content in the world. Billion tons of packaging waste are generated annually due to the use of single-use packaging and throw.

Traditional methods for handling packaging wastes are incineration and landfilling [5]. Incineration is the worst choice for waste treatment due to its releasing greenhouse gases into the atmosphere [6]. Resource recovery from waste is an environmentally and eco-socially friendly practice that can be recovered energy, minerals, fibre, etc. The increasing use of single-use packaging reasons to losses of more than 95% of its economic value [7]. Tetra Pak (TP) and Metalized films (MF) are mostly used in food packaging, and the packaging waste can be reused to produce valuable products without open dumped or incineration after being consumed [8]. TP and MF-based waste recycling reduce greenhouse gas emissions, resource consumption, and solid waste disposal problems [9]. It can be used as a raw material for other valuable products, such as composite panels [10].

Humans are consuming tonnes of packaging each year worldwide. The use of packaging will be increased by 47% in weight by 2025 compared to 2012, according to the estimation of the Ellan MacArthur Foundation [11]. Compared to other municipal solid waste, packaging waste was about 29.5% in 2009 in the USA and 25% in 2006 in Europe [5]. The packaging waste generated by household and producing industries was about 825 million metric tons per year in Europe in 2014. Food and beverage packaging was also large compared to the estimated total consumer packaging used [12]. The global consumer packaging demand ranged from US$ 400 billion to $ 500 billion in 2016 [13]. Especially TP and MF wastes added to the solid waste content of a country [14]. Smart food packaging was expected to increase to $24.65 billion by the end of 2021, with 7.7% annual demand growth from 2011 to 2021 [15]. This study's primary basis was to identify possibilities of made of composite material from packaging waste for various applications to minimize solid waste generation.

II. LITERRATURE REVIEW

Packaging is a tool used to protect goods from environmental factors [16]. Good packaging delivers the goods in the best conditions to the consumer. The packaging is also providing good storage media [17]. The consideration of food packaging is essential to minimise food waste and losses by protecting it from spoilage and contamination [18] [19]. Packaging materials are essential in the beverage industry as well as the food industry. Especially long-time food and beverage storage increases profit and minimises the high risk of waste generation [10]. Paper, paperboards, metal, wood, glass, plastic, and polymer foils are mostly used as food packaging materials in industries [20]. Aseptic packaging was introduced for packaging by adding a polyethene layer and the development continued by applying an aluminium layer to enhance the protection of the stored product [10]. The beverage and dairy industry mostly used TP cartons as the packaging media to protect beverage and milk production [16].

Tetra Pak and Metallised Film Packaging:

TP packaging is widely used as an aseptic packaging in the beverage and liquid food industry. Especially TP cartons are widely used as a container for milk, wine, juice, and soft drinks [21]. TP cartons allow products to be distributed without refrigeration for a long time without spoilage [22]. TP containers maintain the nutritional quality and hygiene of the foods [23]. Ruben Rausing started the development of milk packaging in 1943. It was the TP's starting; the name was born in 1944 due to its tetrahedral shape. TP cartons are used since milk foams fill, reasoning transportation and storage savings. TP developed the aseptic sterilisation technology for bacteria-free milk in 1961. It expanded to store the products for up to six months without refrigeration using the UHT (Ultra High Technology) pasteurisation process [24].

TP is a combination of Aluminium foil and polyethene-coated papers that results in a six or five-layer composite. TP consists mainly of three materials, namely paper (Cardboard/ Kraft paper), Low-Density Polyethylene (LDPE), and Aluminium (Al) foil. These materials are organised into six-layer concerning 70-75 wt.% of paper, 20-25 wt.% of LDPE, and 5% of the Aluminium layer [24, 27, 28, 29]. Polyester (PET), Polyethylene (PE) and Polypropylene (PP) are the most used polymer for producing multilayer film [28]. The layers of the TP carton are shown in Fig.1.

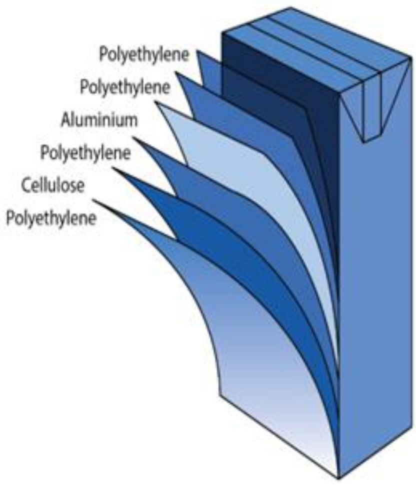

Fig. 1. Layers of a Tetra Pak carton

Paperboard is the primary material of TP packaging that provides stability to the carton. The TP carton's strength can vary according to the type of paperboard and provides a smooth printing surface [29]. The polyethene layer of the TP carton prevents the food from contacting the aluminium layer. The Aluminium layer of the TP is provided with a barrier against Oxygen, light, and loss of flavour [30]. The Al layer assures the prevention of the food content by preventing the penetration of microorganisms [25]. The type of paper used for manufacturing TP cartons depends on the product being packaged and the type of industry. Glues or hot melts are not added to gather all layers, and the temperature is responsible for gathering these layers of a TP carton [27].

MFs uses to produce flexible packaging. More than 65% of MFs produce packaging materials [31]. Metal-containing materials are widely used due to the proper barrier of air and moisture [32]. The packaging films comprise various thin layers depending on the application, and these layers should be as thin as possible for cost reductions [33]. Metalized plastic waste films are polymer-based and contain a coated aluminium layer. These polymeric and aluminium layers are combined mechanically and chemically by air emptying [34]. Here, the Aluminium layer limited any leaching of packaging [35]. Aluminium powder is widely used to produce laminated metal packaging as a protective coating, and the use of Aluminium powder will exceed 3.9 billion USD by 2025 [36].

Packaging waste recycling:

Reaching sustainability is not straightforward due to the lack of resources with respect to the requirement. Transitioning the circular economy from the traditional linear economy shows the correct way to achieve sustainable goals [37]. Waste generation creates environmental and financial impacts due to cost increases for waste management [38]. The circular economy concept extends products' lives through reuse, energy recovery and recycling [39]. Minimising waste, energy inputs, and material is the main target of the circular economy within choosing the industrial loop instead of the traditional linear economy [40]. Recycling is the recovery operation of recyclable waste materials to use as raw material for another purpose. Recycling consists of a set of processes and classifies into different aspects. Recycling can be done as production recycling, material recycling, and feedstock recycling according to the degree of processing [41].

The degradation of Multi-layered packaging (MLP) is more slowly and pollutes the soil and water bodies. As well, leakage of contaminants will accumulate the marine organisms [42]. Considering the end life of packaging is essential when producing packaging materials. One way to minimise the environmental impact of packaging is to use ecologically designed packaging [43]. Biopolymer-based packaging materials allow for minimising waste disposal problems due to their ability to biodegradability. A lot of scientific studies have reported that industries tend to the bioplastic and nanomaterials for packaging materials. But the high cost of bioplastic is limited by the widespread commercial application [5]. Another factor is that most innovations are less eco-friendly than expected [44]. Although biodegradable materials are options to be considered for environmentally friendly packages, consumers do not always understand when selecting an item [45].

Recycling packaging waste can be considered an energy recovery option to reduce packaging waste. The polythene-Aluminium packaging layer consists of about 40 MJ/kg of caloric value and can be used as an attractive fuel [46]. But incineration is a negative impact on the environment [47]. Reducing may be the best option to minimise waste generation, but we cannot stop the usage. Reuse decreases required new products and reduces raw materials and energy-consuming costs for a new product [41]. Recycling and reuse of waste

Volume 7, Issue 1, pp. 1-9, 2023. ISSN (Online): 2456-7361

packaging are saved resources and energy and help to minimise the environmental impacts of material use.

Waste recycling is one of the necessary aspects of a waste management system that ensures the recovery of value and maximisation of profit of a product [48]. For example, recycling one ton of paper from waste avoids cutting down 17 trees for paper production. It also reduces 6553 gallons of water and 463 gallons of oil for paper production and energy requirement [49]. Packaging materials can be utilised to produce valuable products as a filler for other products like polymer concrete and oriented strand boards [46]. Especially, TP and MF waste can be used to produce composite materials increasing the end life of the packaging materials [12].

Manufacturing of composite materials using industrial waste:

Material production combines two or more different types of materials introduced as composite materials. The main components of composite material are reinforcement, matrix, and interface region. The materials used for composite material production have individual properties. Normally, composite materials are low density compared to bulk material's strength. The reinforcement is usually fibre or a particle that acts as the discontinuous or dispersed phase. Fibre is mostly used to produce high-strength composite manufacturing because of its high aspect ratio (length to diameter). Normally the reinforcements are harder and stronger than the matrix. Polymer, metal, or ceramic are mostly used as matrix materials [50].

Advantages of composite materials:

1. Composite materials reduce the weight of a product. This property is resulting in saving maintenance costs like transportation.
2. It can change the optimum strength and stiffness by changing the material composition.
3. It can produce corrosion resistance products changing reinforcement and matrix materials.
4. It reduces assembling costs.
5. Can produce different types of shapes (Design flexibility) [51].

Composite materials are used widely in the world, reasoning the functions of composites. Most composite materials are used in construction applications, transportation applications, medical applications, and day-to-day applications [51]. Especially, marine construction and boat manufacturing industries use fibre polymer-based composite due to its workability and durability [52]. Composite materials are widely used for ceiling panels, outdoor deck flooring, doors, railings, fencing, boxes, benches, mobile panels, windows, cladding, toys, and landscaping work [53].

The world's industries produce massive amounts of waste and by-products from their process. The waste generated from the industries uses to produce composite material by adding value to industrial waste. Wood-plastic composites (WPCs) are widely used in the wood composite industry, giving value to wood waste. Wood is an excellent filler material that can be used for thermoplastic production. WPCs are made using thermoplastic with suitable wood fibre and a considerable amount of coupling agents. The interfacial adhesion between WPC components controls the type of coupling agent used and the amount [54]. The thermal conductivity of buildings' walls is the most critical factor when building a wall, and WPC materials can meet the required performance. For example, a previous study produced a 20 mm thick single-layer WCP wall that performs the required wall thermal level. It also concluded whether double-layered WPC material could meet the standard wall thermal level [55]. In a similar study, five different types of WPC were made using recycled plastic (polypropylene and polyethene) and wood waste. According to the test result, polypropylene-based WCP gave higher tensile strength properties [56]. Sawdust performs well as a reinforcement material. Hence valuable resin hybrid composite produces using industrial sawdust [57]. WPC material was introduced in an earlier study, mixing recycled waste wood fibres with High-Density Polyethene (HDPE) matrix to replace plywood used in ship containers [58]. WPC materials produced using industrial waste with a mesh indicate replacing HDPE panels in the construction field [59]. An interesting study produced acoustic composite material using recycled rubber with sawdust and fresh HDPE to evaluate sound-absorbing properties. The results showed that the acoustic composite's mechanical and physical properties were sufficient for noise barrier application in public traffic [60]. The environmental pollution from textile and synthetic polymer waste can be reduced by using raw materials for composite materials production. The textile waste consists of excellent strength reinforcement cellulose nano-fibrillated fibre capable of producing bio composite film [61]. In a similar study, sound-insulating materials were made using cotton-polyester mixed waste and natural rubber. The study results suggested that the thickness of the composite increases the sound insulation property [62].

Agriculture produces a massive amount of fibre consisting of waste that can be used to manufacture valuable composite materials. Composite materials are produced using straw and bioplastic to substitute polymers used for packing [63]. Banana waste and bagasse waste are highly recommended for to manufacture of low-cost composite materials applied in the construction and carpenter industry [64]. A novel composite material was made using desulfurized gypsum with expanded polythene from industrial solid waste, increasing its thermal insulation ability [65]. Another important waste category produced from agriculture is ash, including rice husk ash, wood ash, and bamboo leaves ash. The researchers proved that these agro based composite materials are applicable to replace conventional construction materials [66].

Recycling of Tetra Pak and Metalized film packaging waste:

MLP represents one of the heaviest pollutions in the environment due to the difficulty of recyclable. Hence most of the packaging materials are processed in sanitary landfilling, incineration or thrown away into natural resources like lakes, rivers and especially to the ocean [28]. Recycling these packaging wastes minimises environmental pollution, and waste management difficulties such as recycling TP packaging contribute to the circular economy providing important sources for other industries. Researchers have reported that the MLP wastes can be processed [67] in an environmentally friendly, and it is possible to use for energy production [28].

Methods for Tetra Pak and Metalized film packaging waste recycling:

Previous studies reviewed the general mechanical approaches for recycling MLP materials. Mainly those strategies can be divided into two categories. The first one is the separation of the different components by the dissolution representation technique or delamination. The delamination can be done physically, chemically, or mechanically [68]. The selective dissolution-precipitation with the hydro pulping recovers material that composes TP cartoons reducing the required energy [69]. Hydro pulping is the mature technology used for paper recovery from TP cartons, and such plasma technology also separately recovers paper, aluminium and plastics [70]. The second strategy is the joint processing of the MLP materials with or without additives. MLP materials can be recycled by combining processing without separating the components. Figure 02 shows an overview of the method of recycling multilayer packaging. Compatibilization is the most appropriate technique for improving the blending performance of the MLP material, and the significant advantage is simplicity. The Compatibilization technique provides an additional life cycle to MLP materials, but incineration is the end-of-life recycled material [68].

Solvent-based approaches are practical for separating aluminium and polyethene in TP cartons. Solvent-based technology recovers all materials from dissolving polythene in an organic solvent. Then other remaining undissolved particles can separate [46]. As metalized food packaging consists of a complex composition, separating layers is challenging and not profitable using mechanical and chemical practices [71].

Reuse and burning are the most popular technologies for packaging waste recycling which can be categorised as primary, secondary, tertiary, and quaternary. Producing a new bucket or similar thing using HDPE from beverage cartons is an example of primary recycling of composite, and converting polyethene terephthalate beverage materials into the carpet, is an example of secondary recycling of composite. Brake down into its chemical building using chemicals is the tertiary recycling, and energy recovering by incineration of the waste composite, such as pyrolysis, is the tertiary recycling of composites [72].

The pyrolysis method is the thermal degradation of organic material at high temperatures in the absence of Oxygen [73]. Pyrolysis technology promises energy recovery and is more effective than solvent soaking and combustion [74]. The pyrolysis process is widely used for the recycling of TP waste, and it is an emerging technology to MLP waste a valuable product [75]. The experiment results of previous research showed that char could obtain from the pyrolysis process and those char is suitable to use as solid fuel [76] reasoning of its high calorific value as well as pure aluminium can be recovered by the pyrolysis process [77]. The applicability of producing char is decided by the pyrolysis temperature [78]. Many heavy hydrocarbons are formed from non-catalytic pyrolysis of the TP over acidic catalysis [79].

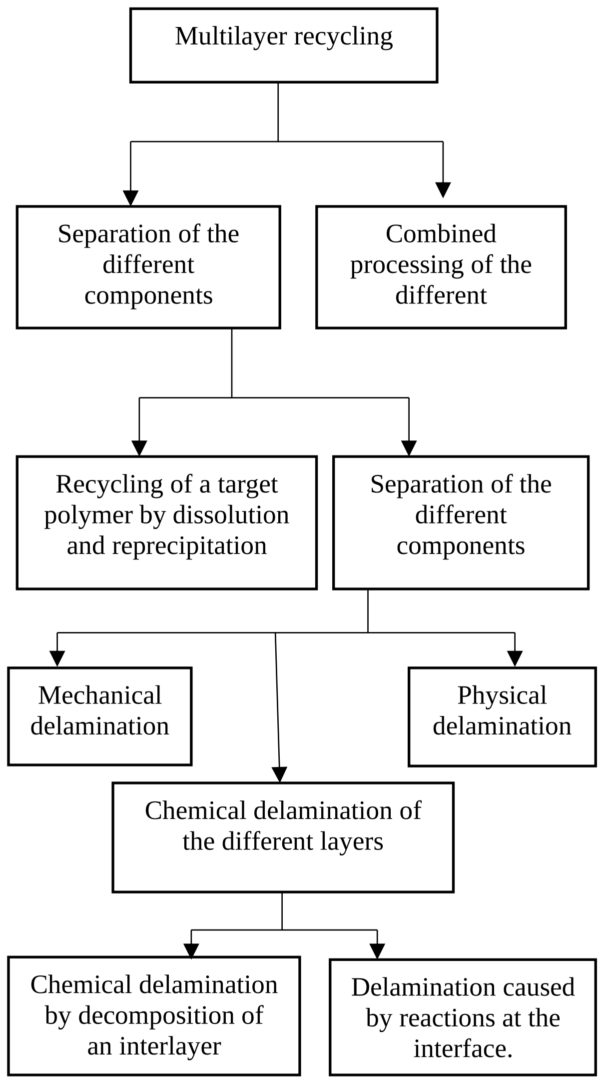

Fig. 2. An overview of the method of recycling multilayer packaging [68]

Hydrothermal treatment can also be used to recycle TP waste. Hydrolysis is better for recovering the monomers from multilayer packaging cartons. Polyethene, Polyester, and Polyimides can be recovered by using the hydrolysis process [72]. In a previous study, the temperature varied between 200 ^{0}C – 240 ^{0}C while the time ranged from zero to 60 minutes and the results showed that a composite of aluminium and Low-Density Polyethylene (LDPE) was formed in the process. The hydrothermal process produces hydro char after the aluminium removal, and the hydrothermal process increases the calorific value of biomass made from TP [80]. Gamma radiation technology can be used for recycling TP waste. The chemical structure and mechanical properties of the cellulose, polyethene, and aluminium of TP waste can be modified by using gamma radiation technology [81].

Compression moulding and injection moulding are the other popular methods for recycling packaging waste materials. Compression moulding limits the shape of the recycling product compared to injection moulding and requires high pressure. Specially compression and injection moulding are used to produce valuable composite materials by using TP waste with other packaging materials nowadays [72]. The pressure and maintenance time are the most influential factors when making a composite material from compression moulding, and also, they are more critical than the temperature [76].

Composite material made from Tetra Pak and Metalized film packaging:

Previous studies were performed on the application of MLP waste, especially TP waste, in the composites industry. Recycled or waste TP can be added to the cement concrete in the construction industry for resource utilisation. But poor adhesion between TP material and cement matrix is a significant problem. A previous study made a concrete mixture using cement, water, gravel, sand, and waste TP. The experimental results showed that the elasticity modulus and compressive strength of the concrete mix had improved respectively by 39% and 30% when the concrete with 10% of lamellae of TP and irradiated at 300 kGy [82]. Brittle materials are made from using wastepaper and TP waste for utilisation in the construction industry. In a previous study, composite materials were made using several types of wastepaper, cardboard, and TP waste with natural gypsum to evaluate their properties. Though there was no considerable difference between the types of composites, the maximum density was the composite made with TP waste, according to the experimental conclusion [83]. Tetra brick aseptic can be used as an addition for porous asphalt mixture production. An experiment result showed that tetra brick aseptic provides similar or higher improvement than commercial cellulose fibres. It also showed that using 1mm-2mm Tetra brick aseptic fibre in a dosage of 0.25 % - 0.50% by weight gave the recommended property for porous asphalt materials [84]. A Concrete composite was made using metallised plastic waste film and palm oil fuel ash in a previous study. The experiment concluded that the produced cement composite reduced the workability of concrete. But it showed whether the MFs increase the linking ability of the concrete mixture and give higher tensile and flexural strength values than those of a plain concrete mixture though at a longer curing time [85, 86]. Consideration of Dimensional stability, fungal resistance, and degradation of the surface of the panels due to weathering are important when making composite panels using TP-based materials. In an interesting study, composite panels were made using waste TP and Zinc borate mixed with 1% and 10% to test biological performance. The experiment results showed that the fire performance of producing composite is improving with the 10% of Zinc borate. The study concluded that a small amount of TP degrades during the thermal application because increasing Zinc borate increases the performance of fire resistance [87].

Wool yarn waste is one of the most generated wastes in the textile industry. In a previous study, hybrid composites were made using wool yarn waste with shredded TPs. The composite panels were made through hot pressing, and the average target density of a panel was $1gcm^{-3}$. Tensile strength, flexural strength, internal bonding (IB), thickness swelling (TS), water absorption (WA), and density of the made composites were tested. The test results showed that the modulus of rupture (MOR) values increase when the wool yarn wastes increase to 15% (85% of TP). According to test results, maximum internal bonding strength showed with 10% of wool yarn waste (90% of TP), and internal bonding strength decreased when increasing the wool yarn waste percentage. The study showed whether there is a possibility to use these produced hybrid composite panels as commercial wood particleboards [88]. Hybrid bio composite panels were made from TP as a sandwich with different skins. Jute woven fabric, glass woven fabric and Polypropylene nonwoven spun-bonded fabric are the other raw materials used for producing composite panels. Those panels are made by hot pressing. The study results showed that the woven fabric made of either Jute or glass has an effect on the MOR value of made composite panels as well as sandwich structure acting as an I-beam structure to increase the MOR value of the composite panels. The properties like thickness swelling and water absorption of produced hybrid bio composites samples were significantly better than the standard commercial particleboard that they used to compare. The study suggested that using those produced composite panels is more economically costly than commercial particleboard [89]. Wool, minerals, polyester, polystyrene, and glass are used as partition wall insulating materials. The insulating panel that is made by TP cartons also can be used as insulating materials for partition wall manufacturing. In an interesting study, three types of insulation panels were made called "Corrupak", 'Colmepak", and 'flat board" to test-fire resistance and water resistance. The study concluded that the panels made were taken more time to heat than the commercial panels. But they are similar to mineral and glass wool used for insulation panel making [90].

In another study, WPCs were made using TPs, Poplar timber powder, and Maleic anhydride-grafted polyethene (MAPE). The samples were made through the injection moulding method, and the test samples were prepared under 10 MPa nozzle pressure at a temperature of 180 ^{0}C. Here, to control the moisture level below 1% of the poplar timber powder, it was dried up to 100 ^{0}C in an oven for about 24 hours. The testing results showed whether the increase of TP percentage from 0% to 30% increased the tensile modulus of the composites, and it also increased with the percentage increase of MAPE. Here, the highest tensile modulus, strength, and impact resistance were shown when the composites contained 3% MAPE and 30% TP [91, 92]. Moreover, in another research, WPC panels were manufactured using TP waste. The testing results suggested that Water absorption of a WPC panel is influenced by immersion time, and Polyurethane coating as anticorrosion coating improves the WPC panel's durability [93]. A study evaluated the fungicide and insecticide properties of the composite panels made from TP overlaid with beech veneer. The study results showed whether composite panels made from TP had a high resistance to fungus and Wood veneer faced panels had higher antifungal and insecticide properties. The study suggested that composite panels can be used as a substrate with wood that cardboard veneer sheets in heavy humidity conditions, and composite panels have lower production costs than those of wood-based panels in the market [4]. In a previous study, the composite board samples were produced using lignocellulosic waste flour and polyethene aluminium (PEAL) with and without MAPE. Here, the experiment results showed that the sawdust flour-filled polyethene aluminium composites had better tensile and flexural properties than the rice husk flour-filled polyethene aluminium composites. Moreover, the results showed that the strength and modulus values of the filled composites are significantly higher than the unfilled composites [94].

Aluminium consists of polyolefin-based material that increases the matrix's thermal-oxidative stability [95]. Composite materials were made in a study using PEAL obtained from recycled TP and ammonium polyphosphate to improve composite materials' flammability and combustion behaviour. The study showed that the thermal stability in the Oxidative atmosphere of the made material is improved [96]. The composite panels were made using recycled TP cellulose with biodegradable polybutylene succinate. It was provided biodegradable quality in soil under composting conditions. The panel consists of polybutylene, and 10wt% to 50wt% recycled TP increases the hardness and young's modulus values of the composite compared to the neat polybutylene succinate [97].

The composite panels were manufactured using TP, Candy polyethylene wrappers (CPEW), and food packaging films (FPEF) in a previous study. Their target density was 900 Kgm^{-3}, and there were no additional binding agents for manufacturing the composite panels. The raw materials were dried to 10% moister content, and composite panels were made by high-pressure compressing. The study hoped to study MOR, screw-holding strength, thickness swelling, and water absorption of the produced composite panels. The testing results showed that the highest MOR value was determined for the samples having 40 % Tetra-Pak and 60 % CPEWs. The panel's thickness swelling and water absorption were reduced when the decreasing of TP and increasing FPEF and CPEW percentages of the composite panels [98] [26]. In another interesting work, TP-based panels were made by using hot pressing to evaluate the biological performance of the panels. The study results showed that the panels were resistant to fungi and termites. Here, the experiment results found that the paper layer's thermal degradation and LDPE layer began to occur at temperatures between 200 ^{0}C to 350 ^{0}C and 432 ^{0}C. The aluminium layer was not degraded during thermal treatment. The results suggested that it is possible to use panels produced from TP for outdoor applications, and biocides can be incorporated into such panels to increase biological resistance against fungal degradation [99].

TABLE 1: Composite materials made using waste material and obtained results.

Composition	Properties								
	Density (Kg/m^3)	Water Absorption (%)	MOE (N/mm^2)	Tensile Strength (N/mm^2)	Thickness Swelling (%)	MOR (N/mm^2)	Compressive Strength (N/mm^2)	Impact strength (kJ/m^2)	Screw holding strength (N/mm)
TP/FPEF/ CPEW [26]	900	4.3 – 15.3	NA	NA	4.3–12.3	8.7–15.5	NA	NA	130 - 179.8
TP/WF/LDPE/MAPE [91]	Not Available	NA	1.06 – 2.36	19.31 – 26.95	NA	NA	NA	35.0 – 42.67	NA
TP/ Wool [88]	730 - 790	5.0 – 22.0	3.68 – 4.0	4.54 – 5.4	2.2 – 7.5	11.41- 15.1	NA	NA	NA
Recycled plastic/ wood/ MAPE [56]	NA	≤ 2.3	661 - 2530	5.5 - 37	≤ 3.6	29.4 – 46.2	NA	≤ 10.5	NA
The palm oil fuel ash/ MF/ Portland cement [106]	NA	4.1 – 5.2	0.023 - 0.028	NA	NA	2.51 – 3.96	20.5 – 44.89	NA	NA
TP/ Glass woven fabric/ polypropylene. [89]	0.83 – 0.96	6.52 –19.33	NA	NA	0.97 – 5.33	9.75 – 22.67	NA	NA	NA

In another study, composite materials were produced using TP, multicolour high-density polyethylene (HDPE), and single-colour HDFEs. Here, post-consumer HDPE bottles were used for composite manufacturing, and they were produced by hot press. The study results showed that HDPE strongly influences the mechanical properties of the composites. The degree of crystallinity and mechanical modulus varies among different coloured HDPEs, and there was poor adhesion between HDPE samples with different colours. The study suggested that improving processing parameters on recycled HDPE can open up the opportunity to generate high-value composite materials with mechanical properties suitable for structural applications [100]. The mechanical and physical properties of composite panels made from TP waste with HDPE are higher when extending the processing time. The amount of HDPE affects the mechanical properties of composite material [101]. Previous studies determined that the nature of the pigment influenced the mechanical behaviour of composite materials made from multicolour HDPE with TP and composite made from single-colour HDPE with TP. A previous study showed that the crystallization rate depends on pigment utilization [102]. Flame retardancy is a significant factor when selecting composite materials for industrial applications. One study developed flame retardancy thermoplastic composites using TP waste, HDPE, Ammonium polyphosphate, and Melamine. Here, MAPE was used as the additive material. The experiment results showed that fire retardant load positively affected the fire retardancy of the composites [103]. Some research studies showed whether composite panels' water absorption and thickness swelling decrease with the reduction of TP particles [104]. According to the literature review data, some properties of composite materials made from waste materials are shown in Table 01. Table 01 data shows that using MF reduces water absorption and thickness swelling values. As well as, the tensile strength of producing composite materials will be increased due to consist of Al in TP cartons and MF packaging [91]. Then, the use of MF waste as the second filler material will increase the tensile and compressive strength of the composite materials. The MAPE is an excellent binding agent, and consist of MAPE in producing composite materials also increases the mechanical and physical properties of the composite materials [91]. Likewise, HDPE is also an excellent binding matrix. Epoxy resin has good tensile strength and conductivity properties and uses a sealer. The layering of epoxy resin can improve a composite material's mechanical qualities, chemical and thermal resistance, and water resistance ability [105].

III. CONCLUSION

Because packaging waste is generated due to the high demand for food and energy, many researchers have focused on manufacturing composite materials using packaging waste to increase the end life of this waste. Composite materials, including Tetra Pak waste, are one valuable material that can be used as a substitute for structural and non-structural applications. The findings indicate that optimizing processing parameters on recycled Tetra Pak and Metalized film packaging waste can lead to the production of high-value composite materials with required mechanical properties. The composites' properties depend on factors, including material type, mixing ratio, mixing time, material size and technology, etc. However, various technologies can produce new composites, and compressive moulding is popular. Several studies have revealed that the Aluminium layer of the Tera Pak and metalized film can reduce the water absorption quality. As well as the high cellulose content of tetra Pak reduces the required quantity of other reinforced materials. MAPA and HDPE increase the bonding capacity of composites in accordance with previous studies. Moreover, Tetra Pak increases a composite material's density, thickness, swelling, elasticity modulus, compressive strength, etc. Manufacturing new composite materials using packaging waste minimizes environmental pollution and saves waste management costs.

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Volume 7, Issue 1, pp. 1-9, 2023. ISSN (Online): 2456-7361

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