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Injection Moulding of Recycled Plastic Materials for Hazardous Waste Management in Libya: A Review for Sustainable Manufacturing

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استخدام قوالب الحقن للمواد البلاستيكية المُعاد تدويرها لإدارة النفايات الخطرة في ليبيا: مراجعة نحو تحقيق التصنيع المستدام

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Abstract

Injection moulding is one of the most versatile and important processes for the mass production of complex plastic parts. It is widely regarded as the primary method for producing plastic components with diverse shapes and applications. This study illustrates the recycling of plastic materials, demonstrating that recycled plastics can be reprocessed using an injection moulding machine. The main objective of this study is to review and present research on the number of times various plastic materials can be recycled through the injection moulding process while maintaining acceptable quality and reliability. This is achieved by adding a controlled percentage of fresh (raw) material to the recycled plastic. The study focuses on determining the most effective processing conditions at each stage of the recycling process to optimize material performance. Furthermore, this review seeks to identify optimal processing conditions at various stages of the recycling process in order to enhance manufacturing efficiency, reduce plastic waste, and support the principles of environmental protection and sustainable manufacturing. This study is particularly important for Libya, where rapid urbanization and weak waste management systems have worsened plastic waste challenges. The lack of recycling systems and reliance on landfilling and open burning highlight the need for sustainable solutions. The findings show that improved recycling processes can reduce hazardous waste, enhance resource efficiency, and support environmentally responsible manufacturing.

Keywords: Injection moulding, plastic recycling, sustainable manufacturing, mechanical properties, environmental protection.

الملخص

يُعَد قولبة الحقن من أكثر عمليات التصنيع تنوعًا وأهمية في الإنتاج الضخم للأجزاء البلاستيكية المعقدة، حيث تُستخدم على نطاق واسع لإنتاج مكونات بلاستيكية بأشكال وتطبيقات متعددة، وتتناول هذه الدراسة موضوع إعادة تدوير المواد البلاستيكية، مع التركيز على إمكانية إعادة معالجتها باستخدام تقنية قولبة الحقن. يتمثل الهدف الرئيسي لهذه الدراسة في استعراض وتحليل الدراسات والأبحاث المتعلقة بعدد مرات إعادة تدوير مختلف أنواع البلاستيك عبر عملية قولبة الحقن، مع الحفاظ على مستوى مقبول من الجودة والموثوقية، ويتحقق ذلك من خلال إضافة نسب محددة من المواد الخام إلى البلاستيك المعاد تدويره، بما يساهم في تحسين خصائصه، كما تركز الدراسة على تحديد ظروف المعالجة المثلى في مختلف مراحل إعادة التدوير، بهدف تحسين أداء المواد وتعزيز كفاءة العملية التصنيعية، وكما يساهم ذلك في تقليل النفايات البلاستيكية ودعم مبادئ الاستدامة البيئية والتصنيع المسؤول، وتكتسب هذه الدراسة أهمية خاصة في ليبيا، حيث أدى التوسع الحضري السريع وضعف أنظمة إدارة النفايات إلى تفاقم مشكلة النفايات البلاستيكية، كما أن غياب أنظمة فعالة لإعادة التدوير، والاعتماد على أساليب غير مستدامة مثل الطمر والحرق المكشوف، يبرز الحاجة الملحة إلى تبني حلول بيئية مستدامة، وتُظهر نتائج الدراسة أن تحسين عمليات إعادة التدوير يمكن أن يسهم في تقليل النفايات الخطرة، وتعزيز كفاءة استخدام الموارد، ودعم المسؤولية البيئية في قطاع التصنيع.

الكلمات الدالة : القولبة بالحقن، إعادة تدوير البلاستيك، التصنيع المستدام، الخصائص الميكانيكية، حماية البيئة.

1.Introduction

Plastic waste, particularly when contaminated or chemically complex, can be classified as environmentally and health-hazardous waste if not properly managed. Inappropriate disposal practices, such as open burning and uncontrolled dumping, lead to the release of toxic substances into the air, soil, and water, posing significant risks to ecosystems and public health. In this study, recycling has emerged as a key strategy to mitigate these impacts by reducing reliance on landfilling, conserving natural resources, and minimizing pollution. Mechanical recycling, especially through injection molding, is among the most widely used methods for reprocessing thermoplastics. However, repeated recycling cycles may result in the degradation of material properties, reduced product quality, and the potential emission of harmful compounds. This study aims to examine the role of injection molding in plastic recycling within the framework of managing environmentally and health-hazardous waste. It focuses on evaluating the effects of repeated recycling cycles on material properties, identifying optimal processing conditions, and analyzing the associated environmental and health risks. Furthermore, the study seeks to explore opportunities for integrating these technologies into waste management systems, with particular emphasis on Libya, where there is an urgent need for effective and sustainable solutions. Every year there is an increase in the amount of plastics formed by all types of processes, such as extrusion moulding, blow moulding, film moulding and injection moulding, etc. The recycling of waste plastic materials is developing at a manufacturing process scale, and its aim is to increase further the sales of plastic products by reducing raw material costs. However, this economic argument is only one of the reasons why it is important to recycle these materials. The other is environmental. The main objective of this study is to introduce the studies topic and explain the aims of the work. A general introduction to the themes in the study is followed by an explanation of the study objectives. Each time an item of plastic material passes through the manufacturing process, its quality is reduced. Some plastic material can be recycled over and over again. This study concerns the number of times formed by the injection moulding process can be recycled. The study focuses on the quality of the material after each recycling operation. Material was passed through the forming process up to three times. Also, since it is possible to improve the quality and reliability of the reject's material, by adding a percentage of fresh “raw” material, the study included an investigation to optimise the recycle plastic materials. A review of what constitutes studies is also undertaken, and the link between percentage of fresh “raw method and inputs injection mould machine for the effect of the recycling process on the quality products at each stage is considered. An examination of the theoretical foundation that underpins the study follows, and this discussed in relation to the methodological literature. To this end, this study describes the approach used in this study and the link between theory and practice. An outline of the significance and contribution of this study is then provided, followed by the outline structure of the study. The recycling materials is a significant process to helpful a protecting to landfills, which in turn decreases soil and

water pollution. Reusing materials such as paper, plastic, and metals also reduces the need to extract natural resources. Therefore, recycling is considered an effective tool for achieving sustainable development and environmental protection [1]. A recycling conserves natural resources by reusing materials such as Plastic paper, glass and metal, thereby a maintained of economic value [2]. The recycling materials has become reduces air and water pollution, resulting in cleaner environments and improved public health [3]. This study highlights the importance of using plastic waste recycling and recovery methods, including injection molding, in terms of both environmental impact and economic feasibility. It is particularly significant in defining the role of injection molding within plastic recycling technologies [4]. The review study provides a dressing to the environmental and economic impacts of waste management strategies. The findings support the use of recycling and injection moulding as environmentally acceptive and economically viable solutions for managing plastic waste [5]. This study addresses one of the key economic challenges in plastic waste management to improving mechanical property consistency, the study enhances the economic value and industrial acceptance of recycled plastics, supporting their wider use in injection moulding applications and reducing environmental waste through higher recycling rates [6].

2. Background and Methodology

2.1. History and Background of Recycling Plastics

The plastics industry is one of the fastest growing major industries in the world. Every year in thermoplastic materials, there is an increased level in the amount of plastics used in all types of products. Over the past 20 years, recycling of plastics materials, (RPM), has grown and increased dramatically. This is important not only from the point of view of recycling rejects but also from the economic perspective and marketing of the plastics industry since recycling allows energy and materials to be reused and creates development [7]. Income recycling rates are currently rising fast [8], Also, recycling of plastic reject would reduce the cost of operation processing [9]. The recycling of plastic industrial reject materials has been taking place for decades in the United States. While there is no documented evidence as to when the recycling of plastics first came about, a form of such was always utilised by the plastic industry [10]. Plastic recycling has become an established national industry [11], Plastic industry in the United States is now in its second century, the most important developments having occurred since 1910 [12]. The number of plastics recycling businesses has trebled since the 1990s, with more than 1,700 businesses, which are handling and reclaiming plastic providing support both economical and environmental and are responsible for sustaining plastics industry and related organisations. The plastics industry invested more than $1 billion to support increased recycling within the United Sates in that period between 1990 and 1998 [13]. More than 1,000 quality products made with packaging from recycled plastic are now commercially available [14]. Currently most plastic recycling in the UK entails processing of reject material from industry and municipal sold west, i.e. polymers left over from the production of plastics. This is a relatively simple and economical approach to recycling, as there is a regular and reliable source and the material is relatively uncontaminated. Process scrap represents some 250,000 tonnes of plastic waste extracts in the UK and approximately 95% of this is recycled. This process is usually described as reprocessing rather than recycling [15]. Since the 1950s, plastics have grown into a major industry, which impacts our lives in providing improved packaging to giving us new textiles and to permitting the production of useful new products. In fact, since 1976, plastic has been the most used material in the world and was recently voted one of the top materials [16]. The plastic process industry has been modified and developed in numerous ways, and now there are different types of mould equipment’s used in manufacturing plastic products [17]. That market orientation is an important determinant of business performance as there is a positive relationship between market orientation and sales growth [18]. A modern system for the development and manufacturing of new products are strongly connected to market demand [19]. In this investigation a comprehensive study on the state -of- the recycling plastic materials and a focus on the quality of recycling products were carried out. This issue can be translated into a generic question: How to develop a quality product of the recycling process so that they are able to perform their quality tasks involving several recycling stages, in the manufacturing plastic industries. This anomaly sets the scene for the work presented in the study. In this study is based on a study, which investigates the effects of the recycling process of plastic materials on the quality of the resulting recycled products finished at several recycling stages. Fig. 1. shows the recycling steps of the plastic process.

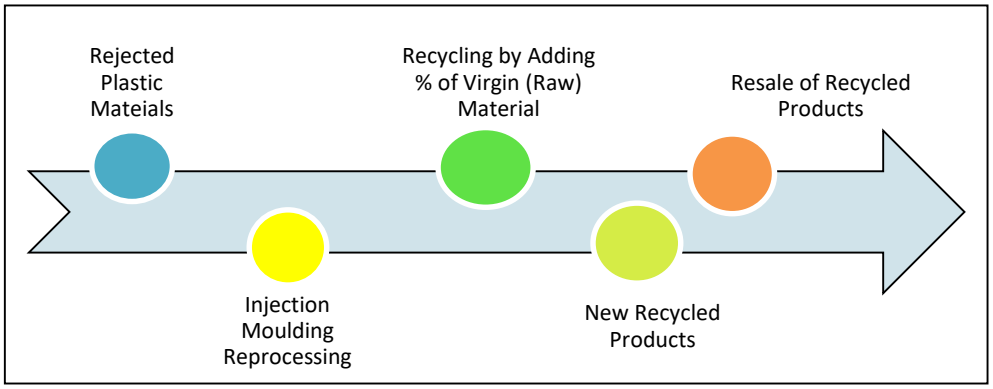

Fig. 1: Recycle steps of plastic process [19].

Recycled plastic would assume a greater share of the markets; the primary question is aimed at identifying which of the parameters reduce the quality of recycled products in the plastic industry. This data has been plotted to show the best recycling materials, thereby greatly enhancing the overall impact and providing a much more intuitive link between the moulding machine parameters and the products quality at each recycling stage. In this study, the proposed concept involves quality sensitivity analyses by considering the process parameters as variables to define the relationship between process parameter variation and final product quality. Recycling is likely to reduce environmental burden since it reduces virgin material production in general [20-21]. Recycling is the recovery of the economic value and energy of reject materials. It can also be of industrial reject and any numerous other types of reject [22-23]. The plastics industry as a whole will have to encompass a viable secondary or tertiary recycling capability. The environmental setting for the plastic industry is such that the existing plastics recycling industry has undergone substantial expansion and development since 1980. This opinion is partially supported by the prediction of a recent survey on the future of the plastics industry [24].

2.2. Thermoplastic materials used in industry

The materials studied, include the most common types of traditional thermoplastics material used in the manufacturing plastic industry, and in durable products such as those described in Table 1.

Table 1: Various thermoplastic materials used in industry [20].

No.	Code	Materials Name	Applications
1.	PP	Polypropylene	Pipes and pipefitting, beer bottles create shells, capacitor dielectrics, cable insulation twines, ropes, bags, food packaging, fibres, table and chairs, etc.
2.	PS	Polystyrene	Packaging, lighting fittings and toys, containers food, foam and coups, etc.
3.	PE	Polyethylene	Food containers, milk bottles and plastic food bags, etc.
4.	PVC	Polyvinyl Chloride	Insulation of wire for domestic electricity supply domestic hosepipes and fittings, siding, carpet backing and windows, soles of footwear, bottles, pipe, fittings and packaging sheet are major rigid markets, etc.
5.	PET	Low- density polyethylene	Soft drink bottles, fibres and many other injection-moulded consumer product containers, etc.
6.	LDPE	High-density polyethylene	Low-loss electrical wire covering blow molded and large rotationally molded containers, Bottle, and packaging film, Shopping bags, etc.
7.	HDPE	High-density	Dustbins used to make bottles for, milk, water bottle, juice, and

		polyethylene	laundry products create and mechanical handling pallets, pipe, bags, film etc.
8.	ABS	Acrylonitrile butadiene Styrene	Shelves, sheet, safety helmets, camper tops, automotive instrument panels, and other interior components, pipe fittings, home-security devices, etc.
9.	EPS	Expandable polystyrene	Make foams for packaging and thermal insulation in the building and construction market, etc.

2.3. Types of Recycling

The methods by which value may be regained from waste or used plastics may be divided into three categories:
• Mechanical recycling secondary.
• Chemical recycling tertiary.
• Thermal recovery quaternary
At each level of the original structure, in which the material and then the polymer itself, is further dismantled, it may be argued that reuse is not really a form of recycling, as many materials for instance are intended for repeated use. Mechanical recycling may be primary or secondary, while the third categories have an exact relationship [25]. Due to the mechanical recycling secondary poorer properties of recycled material, some companies establish a maximum percentage of recycled material to be added to raw material, according to the product to be manufactured and their improve quality [26-27], This study involves identifying profitable uses for each recycling stage.

2.4. Utilisation Technology for Recycled Plastics

Recycling of plastic materials is sensible for reducing the cost of operation processing [28]. The recycling of commercial and industrial reject materials from plastic and textiles to metals and paper has been occurring for decades in the United States. Various plastic manufacturers are aware that rejected parts and trim from the fabrication process may be returned to the process to aid on the formation of new plastic products. This procedure, known in the plastics industry as regrinding, can be repeated numerous times, as long as the additional percentage of raw materials produces products with good. Any excess rejects may sell to other smaller firms to enable future utilization /re-processing of the plastic [29]. The plastic process industry has been modified and developed in numerous ways. Now there are different types of mould equipment's used in the manufacture of plastic products [30]. Currently, most plastic recycling in the UK is based on process rejects from industry, such as, polymers left over from the production of plastics. Process rejects represents some 250,000 tonnes of the plastic waste raisings in the UK and approximately 95% of this is recycled. This is usually described as reprocessing rather than recycling [31].

2.5. Recycling as an Economic Activity

The manufacturing plastic companies began to recognise the problems inherent in the recycling polices that over-emphasise the materials supply at several stages, and to see the potential cost saving and other economic benefits that recycling offers. In the early 1990s, a wide range of "market development "policies were adopted by state of market development policies either sought to influence on the profits. Demands, directly through companies purchasing or requiring certain product to process minimum recycling content; promote recycling via taxes, fess, and other pricing instruments [32]. Recycling rates are currently rising fast, with additional action; this trend can be expected to accelerate. Environmental economics suggests how to analyse and rectify these barriers and distortions. The basic scenarios include processing and marketing in each plastic material [33].

Fig. 2 illustrates the integration of economic development and planning between the manufacture of the recycling process and market; financial department in businesses plastics company.

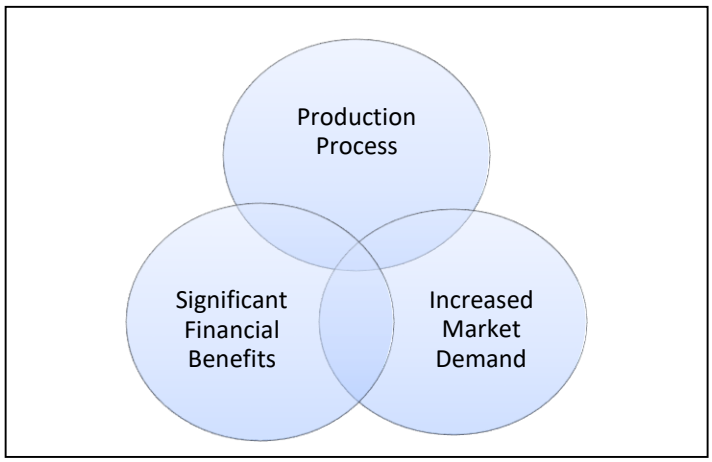

Fig.2: Integration of Remanufacture functions [33].

3. Hazard Assessment of Plastic Waste and Recycling Processes

Plastic waste poses environmental and health risks due to its persistence and the chemical additives it contains, which may be released during decomposition or recycling. These materials are toxic and bioaccumulate. Environmentally, plastics contribute to long-term pollution and generate microplastics through mechanical and thermal processing, contaminating ecosystems and entering the food chain. Improper disposal, such as open burning, releases harmful gases and particles, including volatile organic compounds (VOCs), especially at high temperatures. Emissions are influenced by the material's composition and processing conditions, further increasing environmental risks. Health risks include respiratory and skin irritation, particularly for workers exposed to emissions without adequate protection. Therefore, managing plastic waste requires controlled treatment, emissions monitoring, and appropriate safety measures [46].

4. Literature Review of recycles

This study presents a review of existing literature on the subjects in accordance to the aims of the study that have been outlined in the previous. A critical evaluation of the recycling process in literature and other related areas is undertaken to determine the study work that has taken place, as well as to identify gaps in the, This study provides the reader with a clear explanation to what is involved in this process, and also presents the relevant work that has been done by applying these methodologies to the recycling process using addition of raw materials to recycled PP and also using various mixtures of PP with the other plastic materials.

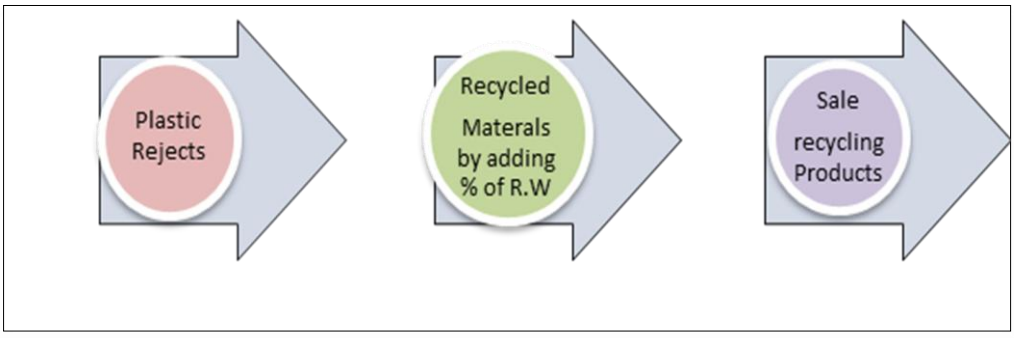

Fig. 3: shows a schematic of the demonstrated reject and sale recycling products [34].

4.1. Review of some Previous Studies on Recycling Process of Mixed Percentage of Raw Materials

Recently, mixing raw plastic materials with the recycled materials would improve the product quality, which would contribute in clear environment [34-35]. The approaches of mixed plastics materials were found to give

better properties [36]. Quality satisfied are most to achieve when recycling the plastic material once or twice [37]. The percentage of raw material in the mixture with the recycled, and the injection moulding process parameters such as mould temperature and barrel temperature, speed etc, are the main factors that would affect the quality of the final product [38-39]. The recycled materials have been correlated with the number of reprocessing steps and compared with those obtained by reprocessing raw materials of the same composition; the properties of the secondary material decreased with the number of mould steps, and the additions of raw materials to the recycled are responsible of obtaining excellent quality, in different plastic materials [40]. Fig. 4 shows recycled materials percentages for various types of plastic materials; thus, it is apparent that PE is the most recycled 31material nowadays and PP has a quit high percentage of recycled material as well [41].

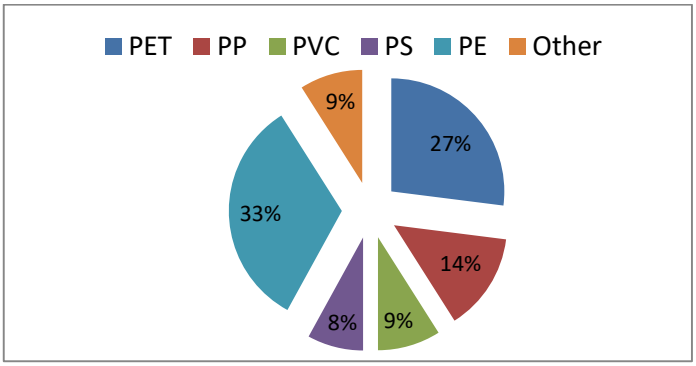

Fig. 4: Different materials that are usually recycled [41].

Martins and De Paoli [38] have presented the extrusion moulding. They were using formulations containing raw material with the recycled plastic materials; the results indicated that the addition of raw material PP has improved the quality of the recycled materials. Aurrekoetxea, et al. [42] have discussed the use of recycling materials by using injection moulding machine model. The recycled materials PP was mixed with the raw PP plastic.

Tall, et. al [41] has developed a mixture of recycled PP with the raw martial PP, of injection moulding process. The results indicated that the mechanical properties were improved by adding percentage of raw materials. Tiganis, et al. [43] have studied the effects of recycling of PP in several times. They investigated the effects of process parameters on the mechanical properties by using injection moulding and a mechanical property was achieved with no significant in the different recycling time. Phinyocheep, et al. [44] has discussed the mixed of raw materials with plastic rejects. Ross and Evans [45] have investigated the mixed materials raw with addition of fibres. The results indicated that good quality was obtained with the fibbers addition.

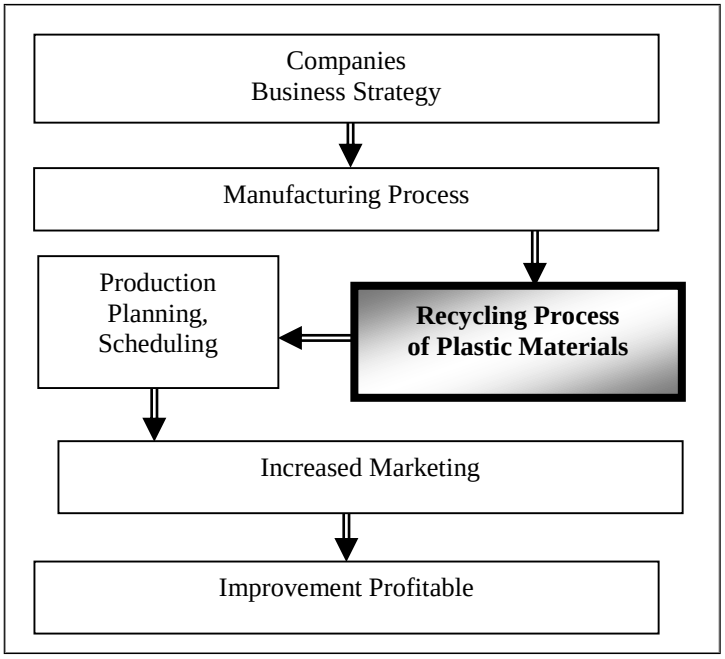

Fig. 5: The link between business, manufacturing strategy and recycling process [33].

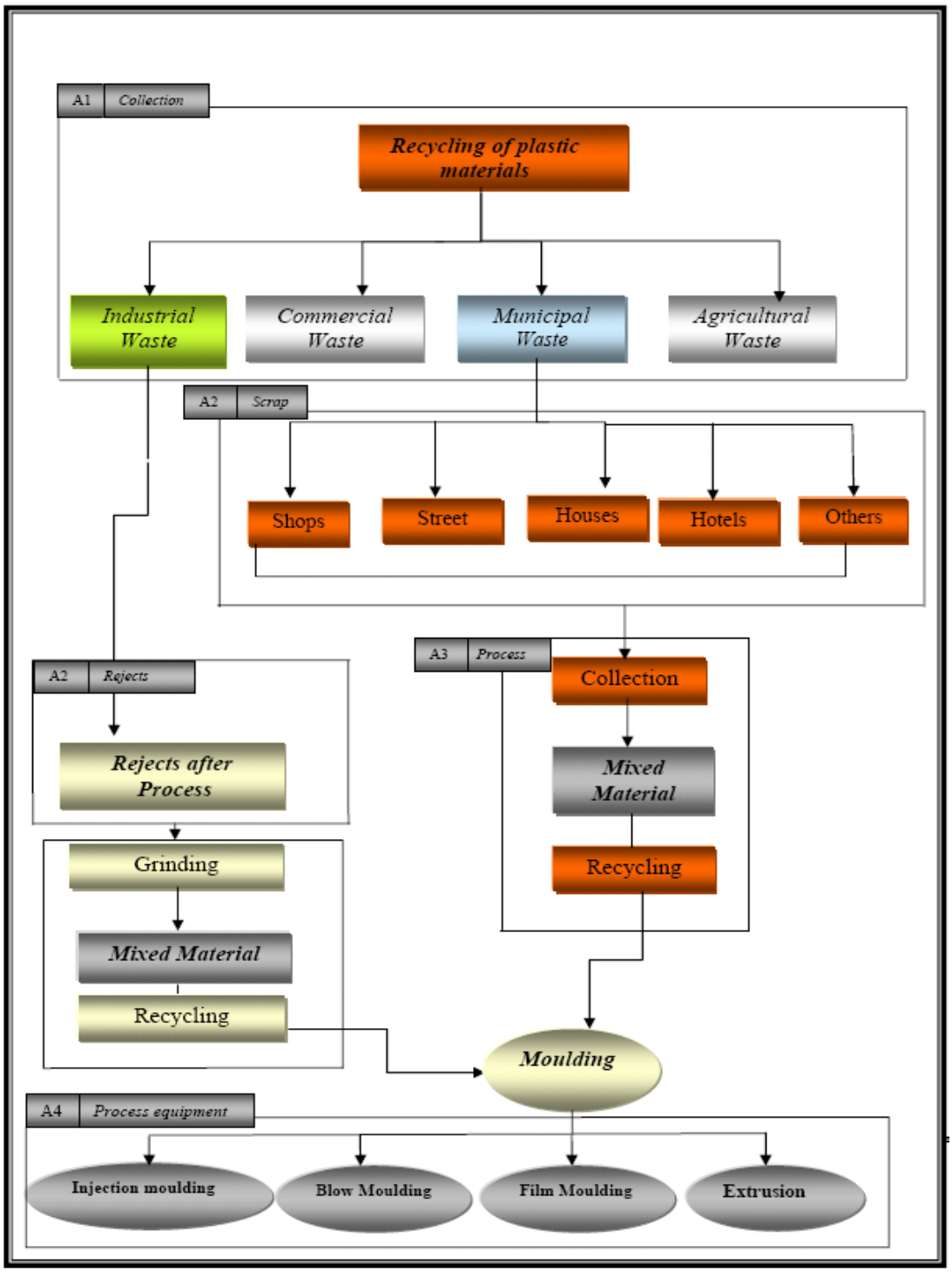

Fig. 6: Schematic of different recycling waste and process mould equipment [46].

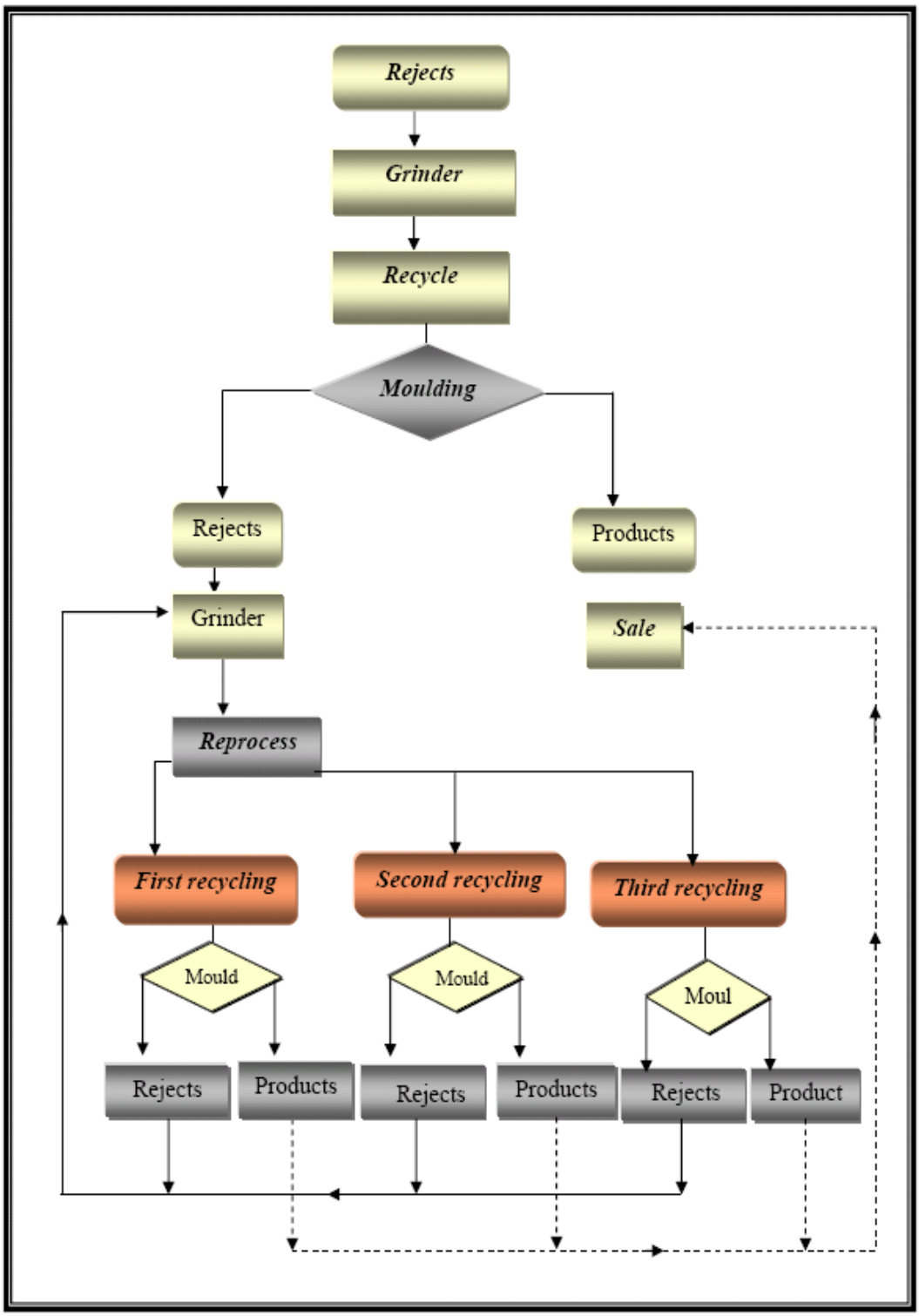

Fig. 7: Schematic diagram of demonstrated rejects and sale recycling [46].

Table 2: Shows different plastic products produced by the mould process [20].

Mould Process	Applications
Injection Moulding	Different types of injection-moulded products, such as, domestic applicable washing machines, dish-washers, air-conditions, office equipment kitchen utensils such as, spoons, knives, forks, kettle, toaster machine. Vehicle moulds include, panel, car lamp housings, automobile filters, car brake sockets and vents and factories mould include combs, syringes, paint brush handles, crash helmets, telephones, mobile phone, gearwheels, brief cases, television cover housings, typewriters, computers cover, keyboard,automotive parts, medical equipment and communication facilities home appliances, pipe fitting , bin ,chair, vegetable box, drawer, baby chair, baby walk, toys , tray mould, MDF floors molding and door hands.
Blow Mould	Different type and size of container and bottles.
Film Mould	Plastic sheet i.e. cups, plate, trays, pipes, house siding, door, window seals and flooring i.e. skirting, end-caps, reducers, T-mouldings, stair noses, and quarter rounds, etc.
Extrusion Mould	Plastic sheet, such as, packing fruit, food, roof sheet garments, textiles, daily-use articles and industrial products, such as, plastic bags in different size and types, plastic films in several forms and formats, paper board and cloth material Ice-pop filling and sealing machines and different size tubes.

5. Plastic Waste Management Challenges in Libya

Libya faces significant challenges in managing plastic waste due to limited infrastructure, the absence of formal waste segregation systems, and weak enforcement of environmental regulations. Rapid urbanisation and population growth have contributed to increased waste generation, while waste collection and recycling systems remain underdeveloped. In many regions, plastic waste is disposed of through open dumping or uncontrolled burning, practices that release toxic emissions and contribute to air, soil, and water pollution. These practices also pose serious public health risks, particularly in densely populated urban areas. Additionally, the lack of organized recycling facilities limits the recovery of valuable materials, resulting in the accumulation of plastic waste in landfills and coastal environments.

The implementation of mechanical recycling technologies, such as injection moulding, presents a practical opportunity for Libya to address these challenges. By establishing controlled recycling facilities, plastic waste can be transformed into valuable products while minimizing environmental and health risks. However, achieving this requires a comprehensive approach that includes investment in recycling infrastructure, development of regulatory frameworks, and increased public awareness of sustainable waste management practices. Transitioning toward a circular economy in Libya will be essential for reducing environmental pollution and supporting long-term sustainable development [47].

6. Discussion

The findings of this study indicate that injection moulding can be an effective recycling pathway within hazardous waste management systems. However, the success of this approach relies on the careful control of environmental

and health risks associated with recycling processes, including emissions, material contamination, and worker exposure. Therefore, proper regulation, optimized processing conditions, and strict adherence to safety standards are essential to ensure that recycling operations are both environmentally sustainable and safe for human health. These technologies enable the transformation of waste into valuable resources, helping to reduce environmental pollution and improve resource efficiency. Moreover, this approach supports sustainable industrial development by fostering local recycling-based industries and creating new employment opportunities.The strategy of developing mixed material is extremely useful for recycled PP. Since PP undergoes a rapid and deep degradation phenomena, with subsequent decrease in mechanical properties. The problem investigated by this study is considered amongst the basic problems, which focus on the quality of the product at different recycling stages. Often during the manufacturing process of traditional thermoplastic materials there is a vast number of rejects (that is, scraps) after the moulding process, although this problem is solved by one of the most common recycling techniques, in mixing raw PP and recycled PP to produce products with desired quality. This practice is very common in industry where plastic rejects are ground and reintroduced into the processing apparatus together with raw material. The main problem related to this practice is choosing the right amount in percentage of recycled PP to be mixed with the raw PP at the mixing stage. Much studies reviews the properties of several percentages mixture, with particular reference to the effects of the amount of the recycled PP used in the mix. A brief overview of the recycled (PP) to predict the properties of mix is also given. As previously outlined, the preparation of mixed PP is, in general, a very useful way of managing plastic recycling. The analysis and prediction of the mechanical properties of PP mixture is extremely complicated, as the different level of parameters used dramatically affects these properties. This is the reason for different in results published previously in literature. This study led to identification to an optimum and subsequent improvement in product quality at varies recycling stages by the various mixed percentages of raw material with recycled plastic materials. In the context of Libya, modern technologies can play a pivotal role in addressing environmental and industrial challenges, particularly in plastic waste management.

7. Conclusions and Recommendations

This study highlights the critical role of injection moulding in advancing both sustainable manufacturing and hazardous waste management. While recycling plastic materials offers clear environmental and economic benefits, it must be carefully managed to minimize risks associated with toxic additives, harmful emissions, and material degradation during repeated processing cycles.

The findings demonstrate that injection moulding can serve as an effective and practical recycling pathway when supported by controlled processing conditions, appropriate material selection, and the addition of virgin material to maintain product quality. However, the integration of such technologies into waste management systems must consider environmental protection, occupational safety, and long-term sustainability.

In the context of Libya, the adoption of controlled recycling technologies such as injection moulding can significantly improve plastic waste management practices. However, this requires a coordinated effort involving infrastructure development, policy implementation, and public engagement.

7.1 Recommendations

Based on the findings of this study, the following recommendations are proposed:

- Technical Measures:
  Optimising processing parameters such as temperature and pressure is essential to reduce material degradation and limit the release of harmful emissions during recycling. In addition, restricting the number of recycling cycles can help preserve the mechanical properties of plastic materials. The use of controlled proportions of virgin material mixed with recycled plastics is also recommended to enhance product quality and ensure consistency in performance.
- Environmental and Safety Measures:
  Plastic waste should be treated as a potentially hazardous material within waste management systems due to the presence of chemical additives and the risk of emissions during processing.

Recycling facilities must implement effective emission control systems, including proper ventilation and filtration units, to minimize environmental impact. Furthermore, ensuring the use of personal protective equipment (PPE) and safe working conditions is essential to protect workers from exposure to harmful substances.

- Policy and Regulatory Actions:
  The development and enforcement of national regulations for plastic waste management in Libya are crucial for ensuring safe and sustainable recycling practices. Establishing clear standards for recycling processes, emission limits, and material quality will help improve environmental performance and industrial reliability. Additionally, promoting circular economy policies can support the transition toward sustainable manufacturing and resource efficiency.
- Infrastructure Development:
  Investment in modern recycling facilities that utilize injection moulding technology is necessary to improve plastic waste management capacity in Libya. Strengthening waste collection, sorting, and segregation systems will enhance the efficiency of recycling operations and reduce contamination. Encouraging collaboration between the public and private sectors can also facilitate the development of sustainable waste management infrastructure.
- Awareness and Capacity Building:
  Raising public awareness about the importance of recycling and environmental protection is essential for improving waste management practices. Educational campaigns can promote responsible disposal and recycling behaviours among communities. In addition, providing training programs for workers in the recycling and waste management sectors will help build technical expertise and ensure the safe and effective operation of recycling facilities.

In conclusion, integrating injection moulding recycling into a structured hazardous waste management system provides a viable pathway for reducing environmental pollution, improving resource efficiency, and supporting sustainable development in Libya.

Reference

[1] United States Environmental Protection Agency. (2023). Recycling basics and benefits (Environmental benefits of recycling). U.S. EPA. https://www.epa.gov/recycle/recycling-basics-and-benefits.

[2] United Nations Environment Programme. (2021). UNEP annual report 2021. UNEP. https://www.digitallibrary.un.org.

[3] European Environment Agency. (2020). The case for increasing recycling: Estimating the potential for recycling in Europe (EEA Briefing 3/2020). https://www.eea.europa.eu/publications/the-case-for-increasing-recycling.

[4] Al-Salem, S. M, Lettieri, P, & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Management.

[5] Jiang, X, & Bateer, B. (2025). A systematic review of plastic recycling: Technology, environmental impact and economic evaluation. Waste Management & Research, 43(8), 1159–1178.

[6] Georgiou, D, Sun, D, Liu, X, & Athanasiou, C. E. (2025). Suppressing mechanical property variability in recycled plastics via bio-inspired design. Proceedings of the National Academy of Sciences of the United States of America, 122(33).

[7] Tavares, M. I. B, & Mothe, C. G. (1998). Material characterization by solid-state carbon-13 NMR: Study of structural polymeric industrial rejects. Polymer Testing, 17, 289–295.

[8] Goldman, T. (1997). Recycling as economic development: Toward a framework for strategic materials planning (Master's thesis). University of California, Berkeley.

[9] American Plastics Council, (2004). Information on plastic and the environment. http://www.Plasticsresource.coni/s plasticseresource/sec.asp.

[10] Vilhena, T. A, & Hemais, C. A. (1995). Recycling of rejects plastics: Economic aspects. In Proceedings of the Brazilian Polymer Congress (pp. 702–720). Rio de Janeiro, Brazil.

[11] Martins, M. A, Mothe, C, & Tavares, M. I. B. (1996). Study on polymer rejects. Polymer Testing, 15, 91–97.

[12] General Directorate for Energy and Raw Materials, Sub-directorate of Nuclear Industry, (2006). Reprocessing, recycling and transport of nuclear material. http://www.indtistrie.siouv.fr/eneraie/anizlais.

[13] Plastics Resource, (2003). Information on plastic and the environment.
http:// www.plasticsresourece.com/s plasticresource/index.asp.
[14] Bevis, M. (1982). Secondary recycling of plastics. Journal of Materials in Engineering, 3, 344–349.
[15] Waste Online, (2004). Plastics recycling information sheet.
http:// www.wasteonline.org.uk/resources/infoimationsheets/plastics.htm.
[16] American Plastics Council, (2003). History of plastics.
http:// www.americanplasticscouncil.ore/s apc/ index.asp.
[17] Clarke, C. R. (2003). Introduction to thermoplastic injection moulding. http:www.crclarke.co.uk
[18] Slater, S, & Narver, J. (1994). Does competitive environment moderate the market orientation–performance relationship, Journal of Marketing, 46–55.
[19] Pepelnjak, T, Gantar, G, & Kuzman, K. K. (2001). Numerical simulations in optimisation of products and forming processes. Journal of Materials Processing Technology, 122–126.
[20] Boguski, T. K, & Hunt, R. G. (1994). General mathematical models for LCI recycling resources. Journal of Conservation and Recycling, 12, 147–163.
[21] Patel, M, Thienen, V. N, & Jochem, E. (2000). Recycling of plastics in Germany. Journal of Conservation and Recycling, 25–90.
[22] General Directorate for Energy and Raw Materials. (2001). Reprocessing, recycling and transport of nuclear material. France.
[23] Mothe, C. G, & Tavares, M. I. B. (1997). Study of recycling and biodegradability of ethylene-co-vinyl acetate rejects by thermal analysis. Polymer Degradation and Stability, 57, 183–186.
[24] Mothe, C. G, & Castor, S. M. (1995). Recycling of polymers (pp. 1–35).
[25] PCN. (2004). Introduction to recycling of polymers.
http://www.pcn.om/Technical Recyclel.htm.
[26] Deanin, R. D, Amran, A, Saraogi, R., & Matani, N. (1983). Recycling of polystyrene. Polymer Preprints, 2, 430–431.
[27] Vosshenrich, B. (1993). Higher proportions of recycled material can be used. Kunststoffe Synthetics, 5, 15–18.
[28] Voute, C. (1994). Recycling Council annual seminar. Birmingham, UK.
[29] Goldman, T. (1997). Recycling as economic development: Toward a framework for strategic materials planning. University of California, Berkeley.
[30] Parker, A. J. (1999). The economics of technological innovation in recycling.
[31] Bennet Europe, (2004). Company information.
http:/ www.bemieteurope.nl/bennet.html.
[32] Murakami, O. (2000). Technology for recycling plastic materials.
[33] La Mantia, F. P, (1996). Recycling of PVC and mixed plastic waste. ChemTec Publishing, Toronto.
[34] Anderson, J. C, Leaver, K. D, Rawlings, R. D., & Alexander, J. M. (1985). Materials science. Van Nostrand Reinhold, UK.
[35] Dow Chemical Company, (2003). Introduction to polystyrene.
http://www.dow.com/stvron/desian/guide/mechanical.htm.
[36] Dintcheva, N. T, La Mantia, F. P., Scaffaro, R., Paci, M., Acierno, D, & Camino, G. (2002). Reprocessing and restabilization of greenhouse films. Polymer Degradation and Stability, 75, 459–464.
[37] Javierre, C, Clavera, I, Ponz, L, Aisa, J, & Fernandez, A. (2006). Influence of recycling material percentage on rheological behaviour of HDPE for injection moulding process. Waste Management.
[38] Martins, M. H, & De Paoli, M. A. (2002). Polypropylene compounding with post-consumer material reprocessing. Polymer Degradation and Stability, 78, 491–495.
[39] Aurrekoetxea, J, Sarrionandia, M. A., & Urrutibeascoa, I. (2001). Fracture behaviour of virgin and recycled isotactic polypropylene. Materials Science Journal, 36, 5073–5078.
[40] Incarnato, L, Scarfato, P, Gorrasi, G, Vittoria, V., & Acierno, D. (1999). Structural modifications induced by recycling of polypropylene. Polymer Engineering & Science, 39.
[41] Tall, S, Albertsson, A. C, & Karlsson, S. (2001). Enhanced rigidity of recycled polypropylene from packaging waste by compounding with talc. Polymer for Advanced Technologies, 12, 279–284.

[42] Tiganis, B. E, Shanks, R. A, & Long, Y. (1996). Effects of processing on the microstructure and melting behaviour of polypropylene. Journal of Applied Polymer Science, 59, 663–671.
[43] Martins, M. H, & De Paoli, M. A. (2001). Polypropylene compounding with recycled material: Statistical response surface analysis. Polymer Degradation and Stability, 71, 293–298.
[44] Phinyocheep, P, Axtell, F. H, & Laosee, T. (2002). Influence of compatibilizers on mechanical properties, crystallization and morphology of polypropylene/scrap rubber blends. Journal of Applied Polymer Science, 86, 148–159.
[45] Ross, S, & Evans, D. (2003). The environmental effect of reusing and recycling a plastic-based packaging system. Journal of Cleaner Production, 11, 561–571.
[46] L. Elgammudi. (2007) Investigation of mechanical properties of recycled polypropylene. PhD thesis, Dublin City University, Dublin, Ireland.
[47] Lgartua, A, Schiwy, S, Hollert, H. and Wagner, M. (2024) Towards realism in hazard assessment of plastic and rubber leachates – Methodological considerations. Journal of Hazardous Materials, 462, p.132-231.