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# Recycling and value addition to thermoplastic wastes to produce plant fibre reinforced composites

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## ABSTRACT

Natural fibres are widely used as reinforcement for thermoplastics to produce composites. In this work, high density polyethylene wastes had value added to them by reinforcing with plant natural fibres (wood flour, rice husks and bagasse) during recycling. The fibres were heated to reduce their moisture content and improve their compatibilities with heated HDPE wastes while binders were used to improve interfacial strength. Composites were prepared by extrusion and tested using universal mechanical testing equipment. The data were analyzed using analysis of variance (ANOVA) technique. The final results for mechanical properties for wood flour, rice husks and bagasse composites respectively were: Tensile strength 83.87 MPa, 74 MPa, and 62.73 MPa; Flexural 26.73 MPa, 39 MPa and 15.22 MPa; Compressive 225 MPa, 190.5 MPa and 140 MPa and Impact strength 78 J/mm2, 81 J/mm2 and 66 J/mm2. The use of binders significantly improved impact strengths and use of fibres added value by cloning desirable mechanical properties to thermoplastic wastes through molecular re-engineering at the interface. Thermoplastic wastes therefore got a second life in form of new value added fibre reinforced products having possible usage for construction works instead of heading for land filling or incineration.



## KEYWORDS

Binders;
Composite;
Fibres;
Recycling;
Thermoplastic wastes;
Value addition.

## INTRODUCTION

The increasing usage of thermoplastics can be observed in our daily life, in uncounted consumer goods around us[1]. Thermoplastics are polymers obtained by addition polymerization and are characterized by ability to be repeatedly softened upon reheating to above glass transition temperature. This quality enables thermoplastics to be recyclable. Thermoplastic products which have undergone a first full service life is regarded as thermoplastic wastes and is ready for recycling. Thermoplastics are preferred as packaging for industrial products as well as for packing of light goods bought in supermarkets. With the instability of Paper Mills in Kenya, most packaging requirements which were formally met by paper packaging products are now catered for by thermoplastic products. Thermoplastic products are nonbiodegradable yet the large landfill space required by them is a major problem. Thereby, the interest on recycled materials developed from post-consumer polymers has gained an increasing attention and a worldwide consideration[2]. The purpose of this research is to recycle thermoplastic wastes to minimize their presence in the environment, avoid incinerating them to minimize production of polychlorinated biphenyls[3], and free their land fill space for other economic utilization.

From information gathered through a questionnaire in Eldoret Municipality in Kenya in the year 2011, its residents release about 19 tonnes of thermoplastic wastes daily to the environment. The largest fraction of these thermoplastic wastes consist of polyolefin such as polyethylene (PE), polypropylene among others, therefore recycling is an alternative destination for them. However, to obtain products having specific properties that are not present in original thermoplastic wastes, it may be necessary to add both technical and economic value to the thermoplastic wastes by reinforcing them with selected plant natural fibres during recycling. The composite materials will have desirable properties of the fibre cloned into the matrix through molecular re-engineering[10]. In most cases using coupling agents such as silanes, titanates and zirconates for stronger interfacial bonds as well as fibre surface treatment by mercerization or acetylation have been successfully researched on[1]. Thus, natural fibres, such as fibres of wood, jute, kenaf, hemp, sisal, pineapple, rice husk, and many others, have successfully been applied to improve mechanical properties of plastic composites[4]. Despite fibre surface treatment and use of coupling agents, plant natural fibre reinforced composites have severe limitations in structural applications due to low impact strengths[5].

The objective of this research is to recycle thermoplastic wastes by adding value to them through fibre reinforcement, addition of binders and use of optimal processing temperatures to produce composites having suitable mechanical properties for possible use for light load structural applications.

In this work, mechanical properties of composites, prepared from post-consumer high density polyethylene (HDPE) as matrix and plant natural fibres (wood flour, rice husks and bagasse) as reinforcement phase, and having either epoxy resin (EP 62-1 and EP 21 LV) or polyurethane resin (X 17) binders have been studied with the aim of improving impact strengths as well as interfacial bond strength for the composite to be suitable for light load structural applications. An optimization process involving use of Anova from initial results was used and optimal products having 42 % fibre weight fraction were then produced for mechanical testing.

## EXPERIMENTAL SECTION

This study was carried out at Moi University in Kenya and involved an area occupying eight estates of Eldoret municipality in the Republic of Kenya and mapped through Global Positioning System (GPS) as shown in Figure 1. The estates were: Huruma, Langas, Elgon View, Milimani, Kapsoya, Mwanzo, Pioneer and West Indies. Questionnaires were administered targeting adult population who were heads of house-holds and also Estates Managers of firms both chosen purposively from eight estates which were deemed to contain information on thermoplastic wastes[6]. The data was collected from 400 respondents using a questionnaire. More data was obtained by directly inspecting the dumpsites in Eldoret Municipality as seen in Figure

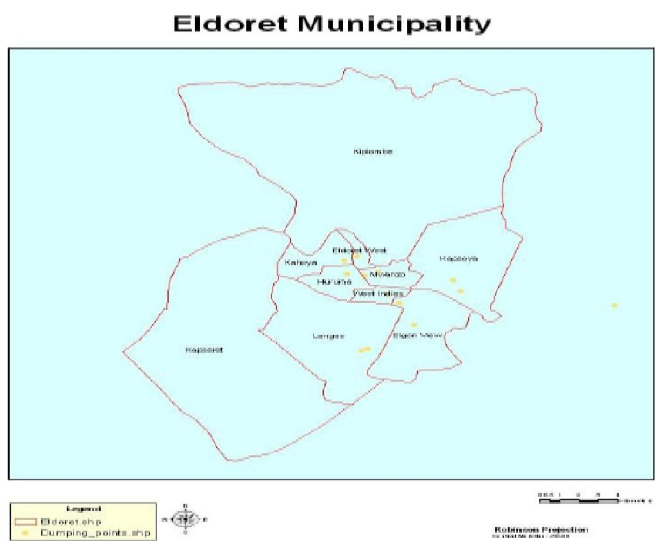


**Figure 1 : GPS map for areas where HDPE wastes were collected from in Eldoret**

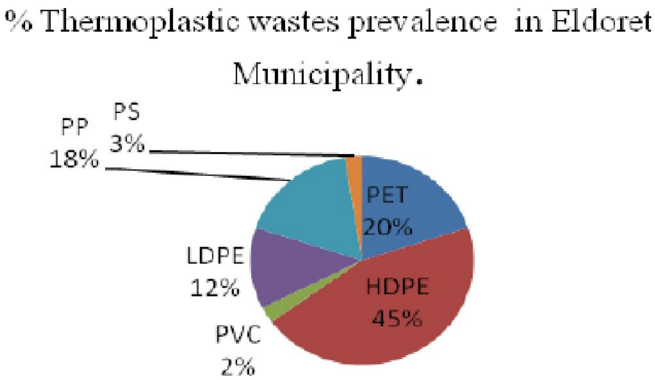


**Figure 2 : Thermoplastic wastes prevalence in Eldoret Municipality, Kenya**

1. The prevalence per weight fractions of thermoplastic wastes available at the dumpsites and at liter bins in the homesteads in descending order were as follows: High density polyethylene (HDPE), Polyethylene terephthalate (PET), Polypropylene (PP), Low density polyethylene (LDPE), Polystyrene (PS) and Polyvinyl chloride (PVC). This information is presented in a pie chart (see Figure 2).

## Waste thermoplastics

High Density Polyethylene (HDPE) thermoplastic wastes were selected for the study due to their prevalence. The selected plastic material collected from Eldoret municipal dump sites was cleaned, dried and shredded to 10 mm by 10 mm size then used for production of composites. The other plastic wastes could be used for batch production in case of full scale production.

## Fibre preparation

Plant natural fibres of wood flour, rice husks and bagasse were used as reinforcement material. Wood flour was collected from Saw mills around Eldoret Town and rice husks were collected from Ahero Rice Mills in Kenya. Bagasse was collected from Chemelil Sugar Company in Kenya where it is produced as agricultural waste from Sugar manufacturing process. Fibre preparation included cleaning to remove any impurities and chemicals, hammer milling (for rice husks), and also choosing of the correct sizes of fibre in terms of diameter and length. This was to give the correct aspect ratio which apart from fibre orientation was to determine the strength of the fibre reinforced composite[7]. The fibre was then completely dried. The fibre length was measured by use of vernier caliper and its thickness was measured by micrometer screw gauge. The size of fibre used for composite production was 1.5 to 5 mm in length and thickness was 0.5 to 0.75 mm.

## Binders

One part epoxy resin (EP 21 LV) i.e. Binder 1, two part epoxy resin (EP 62-1) i.e. Binder 2 and polyurethane resin (X 17) i.e. Binder 3 were used for production of fibre reinforced composites. The aim of using the binders was to improve impact strengths of such composites so as to widen their application to include light load structural usages.

## Research instruments, equipment and tools

Research equipment included shredder, extrusion chamber (fabricated in Moi University workshop in the Republic of Kenya), heating furnace, tongs, extrusion fixture, hand gloves, tape measure, container, hack saw and computer system. A universal mechanical testing machine available in materials laboratory at Eldoret Polytechnic in Kenya was used for compressive, tensile and flexural strength tests. Impact strength tests were done on work pieces using Izod machine also available at the same laboratory.

## Production of coupons

A temperature of $190^0$ C was set on the heating furnace equipment. Shredded mixture of thermoplastic wastes and fibre 1 (bagasse), fibre 2 (wood flour) and fibre 3 (rice husks) mixed with binder 1(one part epoxy resin – EP21LV), binder 2 (two part epoxy resin EP 62-1), binder 3 (one part polyurethene resin – X 17) were prepared in respective ratios by weight of 3.7: 2.1 for waste thermoplastic and bagasse fibre, 3.7: 2.8 for waste thermoplastic and rice husks, 3.7: 3.3 for waste thermoplastic and wood flour. The binder used in each case was 2.5 ml. In each case the mixture was manually filled into the fabricated casing after application of polytetrafluoroethylene (mould release) on the barrel walls, taken into heating furnace and heated appropriately to $190^0$ C for 10 minutes for each combination. The heating was then stopped, furnace cooling was done to $140^0$ C and then the hot fabricated casing full of the mixture was taken to an extruding fixture where extrusion process was done manually by use of a 5 kg

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**TABLE 1 : Anova for three factor for compressive strengths**

| Source of Variation | Fibres,A | Binders, B | Temp., C | AB | AC | BC | ABC | Error | Total |
|---|---|---|---|---|---|---|---|---|---|
| Sum of Squares | 20.81 | 17.92 | 38.4 | 10.9 | 1.56 | 4.23 | 8.73 | 6.96 | 109.5 |
| Degree of Freedom | 2 | 2 | 2 | 4 | 4 | 4 | 8 | 54 | 80 |
| Mean Sum of Squares | 10.4 | 8.96 | 19.2 | 2.73 | 0.39 | 1.06 | 1.09 | 0.129 | 109.5 |
| $F_0 = F_{ratio}$ | 80.6 | 69.4 | 148.8 | 21.12 | 3 | 12.4 | 8.4 | | |
| $F_{cr} = F_{crit\ (table)}$ | 3.174 | 3.174 | 3.174 | 2.55 | 2.55 | 2.55 | 2.12 | | |

**TABLE 2 : Anova for three factor for impact test results**

| Source of Variation | Fibers, A | Binders, B | Temp., C | AB | AC | BC | ABC | Error | Total |
|---|---|---|---|---|---|---|---|---|---|
| Sum of Squares | 7.89 | 34.27 | 23.64 | 3.78 | 1.36 | 6.54 | 0.68 | 5.9 | 84.06 |
| Degree of Freedom | 2 | 2 | 2 | 4 | 4 | 4 | 8 | 54 | 80 |
| Mean Sum of Squares | 3.94 | 17.14 | 11.82 | 0.95 | 0.34 | 1.64 | 0.09 | 0.11 | |
| $F_0 = F_{ratio}$ | 36.19 | 157.2 | 108.42 | 8.67 | 3.11 | 15 | 0.78 | | |
| $F_{cr} = F_{crit\ (table)}$ | 3.174 | 3.174 | 3.174 | 2.55 | 2.55 | 2.55 | 2.12 | | |

weight that extruded about 204 mm length of extrudate of 12.7 mm diameter in 10 seconds. The several air cooled extruded composite products were then cut into the number of test pieces as per the required number of tests i.e. 9 for compressive and 9 for impact strength tests for every combination of the fiber, binder and processing temperature. The experiment was repeated for temperature of $210^0$C and also $230^0$C. The fibre reinforced composite coupons produced were coded and arranged for testing.

## Tests for mechanical properties

### Tests for compressive and impact strengths

Mechanical tests were done using universal mechanical testing machine shown in Plate 1 for all the composite coupons produced at processing temperature of $190^0$C, $210^0$ C and $230^0$ C while impact strength tests were done using Izod impact testing machine.

**Plate 1 : Universal mechanical testing machine**

The mean values of fracture strengths for every three groups for nine tested coupons for every combination of fibre, binder and processing temperatures for each type of test were used in computer software in excel to analyze data. The optimal combination was found to be high density polyethylene mixed with wood flour fibre and polyurethene resin (X 17) produced at processing temperature of $210^0$C. Optimal coupons were then produced under these conditions.

## Data analysis

The method used for data analysis was Analysis Of Variance (ANOVA) for a three factor factorial design to analyze data as well as investigate fibre, binder and extrusion (processing) temperature effects on mechanical properties of the composite. Data was obtained from tests as outlined in section 3.1. Using analysis of variance, ANOVA TABLE 1 for compressive strengths was obtained. Similar ANOVA TABLES for impact strengths were obtained.

From ANOVA TABLE for compressive strengths at 5 % level of significance (TABLE 1), the calculated $F_{ratio}$, ($F_o$) were greater than table values ($F_{crit}$) hence in each case it could be concluded that the fibres, binders and various extrusion temperatures influenced compressive strengths of the composite coupons[8]. They positively affected mechanical properties. From the large $F_0$ for the temperature, it could be concluded that the variation of processing temperature affected the compressive strengths the most[9]. Interaction among factors were greater than $F_{crit}$, they also influenced compressive strengths of the composites.

For ANOVA TABLE for the impact strengths (TABLE 2), the results revealed that binders had most significant influence on impact strengths since the $F_0$ for binder was greater than all the others. All optimal coupons produced at optimal combination were similarly tested and had properties as shown in TABLE 3.

## RESULTS

Optimal coupons with best possible fibre orientation as well as the correct volume fraction of both matrix and fibre ($V_f$ = 42%) mixed with polyurethane resin and produced at $210^0$ C were tested for tensile, flexural, compressive and impact strengths and the results were as in TABLE 3.

**TABLE 3 : Strengths for the optimal coupons**

| S. No. | Optimal waste thermoplastic composite | Mechanical property tested and the results | | | |
|---|---|---|---|---|---|
| | | Compressive strength, MPa | Flexural strength, MPa | Impact strength, J/mm$^2$ | Tensile strength, MPa |
| 1. | Wood flour,$T_2F_2B_3$ | 225 | 26.73 | 78 | 83.87 |
| 2. | Rice husks, $T_2F_3B_3$ | 190.5 | 39 | 81 | 74 |
| 3. | Bagasse, $T_2F_1B_3$ | 140 | 15.22 | 66 | 62.7 |

## DISCUSSION

The entire process of composite production and use includes composition selection, manufacturing process, property investigation and finally engineering application[10]. Rice husks has silica content and this aids in the formation of bonds with the polymer which offers higher flexural and impact strengths compared to that of the other reinforcing fibres. Its composite resists water absorption and hence most resists rot[11]. This makes rice husks most suitable than the other two fibres as the reinforcement phase for composites to be used in wet environment. Wood flour fibre reinforced composite has higher compressive and tensile strengths but it loses its strength faster since wood flour is highly hygroscopic and susceptible to rot[11]. Bagasse fibre reinforced composite suffers from lack of proper adhesion of matrix to fibres since fibres are in bundles and hence this composite has the weakest strength in all the cases. Phase migration occurred and affected the mechanical properties thus lowering tensile, flexural and impact strengths in the all cases. The use of binders increased both tensile, compressive and impact strengths. Fracture surfaces of failed coupons show whether cause of failure was through weak cohesive forces between matrix molecules or the adhesive forces at the interface between matrix and the fibres or fibre pull-out. Value addition to thermoplastic wastes during recycling involved the use of fibres and binders. During recycling, cloning of desirable mechanical properties of the fibre into the matrix took place through molecular re-engineering; superior mechanical properties were hence acquired by the fibre reinforced product[12]. The addition of binders chemically substituted the need for fibre surface modification and therefore enhanced interfacial bond strength. The removal of hydroxyls on fibre surface through heating developed mechanical interlocks of fibre to matrix thus improving interfacial bond strength responsible for superior mechanical properties. Economic value addition was achieved when the thermoplastic wastes which were otherwise destined for land fill or incineration became a highly priced and more durable product after fibre reinforcement and addition of binders during recycling. Due to life cycle advantages during its use (e.g. no need for painting, resists rot, nonhygroscopic), the product could fetch higher price per post than ordinary timber. Environmental value addition was achieved through the elimination of burning of the thermoplastic wastes. This means that the toxic gases such as polychlorinated biphenyls which are released to the environment during incineration of thermoplastic wastes are avoided through recycling and value addition to produce fibre reinforced composites. Technical value addition was achieved through the improvement of impact strengths by the use of binders. With improved impact strengths, the fibre reinforced composites can be used for light load structural applications that include water tank stands, masts for mobile phone boosters, posts for land line telephone wires, interiors of aircraft and also fencing posts for dams, borehole site, pans among other usages.

Recycling and value addition for thermoplastic wastes promote industrialization through building of recycling industries and can spur faster economic growth. Alleviation of poverty through employment available in recycling industries and associated processes can be achieved. Collection of carelessly disposed thermoplastics for recycling helps in the environmental preservation and protection. Malaria, which is a killer disease in Africa, can be reduced by elimination of stagnant water that normally collects on carelessly disposed thermoplastic wastes.

## CONCLUSION

Removal of high density polyethylene wastes through recycling removes 45% by weight of thermoplastics from Eldoret municipality as seen in Figure 2. The use of binders as well as fibres for reinforcement of high density polyethylene wastes improves compressive and impact strengths of the composite and hence widens its applications. The natural plant fibres are therefore economically utilized through their reinforcing function, though they are fully biodegradable. Mechanical properties of fibre reinforced composite is sufficient for light load structural applications. Thermoplastic wastes which would otherwise be destined for land fill or incineration gets both economic, environmental and technical value addition by reinforcement with the fibres and addition of binders to have a new function in the form of high quality fibre reinforced composite product that can be used for multiple functions. Therefore recycling and value addition to the thermoplastic wastes can create faster industrialization through building of small and medium size recycling industries. This will lead to the production of cheaper, stronger and more durable construction materials in the form of fibre reinforced composites and creation of employment opportunities for the youth through collecting, sorting, cleaning and shredding of thermoplastic wastes as well as fibre collection and preparation.

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## SUPPLEMENTARY INFORMATION AVAILABLE STATEMENT

The results from analysis of questionnaire, inspection of liter bins and dumpsites were as seen in pie chart (SI Figure 1). To use 3 factor Anova, the extreme values (fracture strengths) were grouped into three groups and mean of each used for computation as seen in TABLE SI T1. As for impact fracture strengths, mean values (fracture strengths) were grouped into three groups and mean of each used for computation as seen in TABLE SI T2. The graphs for compressive and tensile strengths for optimal coupons were as seen in SI Figures 2 and 3. The fracture surfaces as observed by use of scanning electron microscope were as in SI Plates 1 to 4.

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