Development of Leather Cutting Board from Plastic Waste

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Abstract

Cutting is the process in which goods or garment material are cut and converted into pattern shapes of the goods or garment components. There are two methods of Leather cutting, which are hand cutting and machine cutting. Hand cutting is done with the use of hand knife, cutting board and cutting patterns. Machine cutting can be done using semi-automatic cutting machines or fully-automatic cutting machines. Currently, in Ethiopia, different local and foreign investors are participating in leather products manufacturing. Most of the leather product manufacturing industry and some Small and Medium enterprise's (SME's) in the country are using leather cutting machines in order to cut leather goods or garment parts. Most of the industry and SMEs are using imported cutting board made of plastics and rubbers. However, these cutting boards are expensive.

This research aimed at developing a cutting board made from HDPE (High-Density Polyethylene) plastic waste as main material, calcium carbonate as a filler and glass fiber as a reinforcing material. Primary and secondary data gathering techniques were applied simultaneously. Primary data were collected through interview and field observation. Secondary data was gathered by reviewing different literature. The cutting board developed through collecting HDPE plastic waste, washing, shredding and melting the shredded plastic with filler and reinforcing material. The melted plastic poured in to cutting board mold and cooled. The developed cutting board was compared with HDPE cutting board available in the local market. The developed board showed relative compression and hardness properties with the HDPE cutting board available in the market. In the cost analysis, the developed cutting board is cheaper than the cutting board which available in the market. However, the cutting board in the market has better surface texture and quality than the developed cutting board. Melting HDPE plastic waste using metal or clay cooking pots and charcoal fire is a tedious task and smoke from the fire will cause human health problem and will affect environment. Consequently, manual plastic melting method is not feasible for mass production, because it is difficult to control the amount of heat (charcoal fire) during melting process. Based on this the authors recommend using machine based plastic melting and molding during HDPE and related plastic recycling.

Introduction

Cutting is the process in which goods or garment material are cut and converted in to the shape of the patterns of the component of the goods or garment.[1] There are two methods of leather cutting, which are hand cutting and machine cutting. Hand cutting is method of cutting leather or any other leather product making material with use of scissors and special knifes. This allows producing individual unique items whose value is not determined by functionality but based more on visual effects and design features. Machine cutting is also the method of cutting leather or any other Leather product making material using cutting board and metal dies.[1, 2] Both cutting methods require a cutting board on which to place material for cutting and the board protects the cutting knife and the work surface underneath (such as a desk or table).

The cutting board is certainly a rigid type of board that can be used for a plethora of arts and crafts endeavours. Cutting boards are made of variety materials from wood, tempered or toughened glass and different plastics. Recently the accumulation and potential impacts of plastic pollution has been recognized as an emerging environmental issue.[3-5] Currently in Ethiopia, a huge amount of plastic is generated and some wastes are dumped in landfills. In the country, waste plastics are blocking drainage and sewage systems resulting in water logging, flooding and spread of water borne diseases.[6-8]

To overcome this problem, recycling is a viable alternative in getting back some of the plastic waste for different applications for different household product, packaging, construction materials etc. Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products, sometimes completely different in form from their original state.[9-11] Plastics that can be readily recycled are thermoplastics and can be repeatedly reformed into new products and are the focus of this technical note.

In the country, some Small and Medium Enterprise's (SME's) are engaged in plastic waste recycling for different applications including plastic water containers, plastic cloth washing basins, plastic bags, detergent bottles etc.[12-14.] However, this study focused on developing leather cutting board made from plastic waste and reinforcing materials in order to substitute for imported cutting boards.

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Plastic and plastic board

Plastic boards are usually called PE (polyethylene) cutting boards, or HDPE (high-density polyethylene plastic), the material of which these boards are made.[15] Polyethylene (PE) is the most widely-consumed thermoplastic in the world by volume. Polyethylene is classified by its density and branching. There are two main types of PE; High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE).[16]

High Density Polyethylene (HDPE)

This plastic consists of essentially linear molecules of repeating ethylene units. Its density is 0.94-0.965 g/cc. It has a milky, translucent appearance and is usually used to make bottles for milk, drinking water, laundry products, cleaning and other household chemicals.[17] HDPE Thermoplastic materials become liquid between 120°-180°C. During plastic converting processes, some kinds of additives are mixed with plastics to impart properties. Fillers are relatively cheap, solid inert substances that are added in fairly high percentages to plastics, paints, and paper to adjust volume, weight, costs, or technical performance.[18] They are typically used to lower the cost of plastics. They also significantly increase rigidity and stiffness but decrease both impact and tensile strength. Filler concentration is commonly in the range of 10 to 50% by weight.[19] Calcium carbonate is the dominant filler, accounting for about 70% of the world filler consumption in plastics. Calcium carbonate is white, odorless and tasteless powder with a density of 2.71 g/cc and a Mohs scale of 3. It is used for polyvinyl chloride, polyethylene, polypropylene, silicone and polyacrylate.[18] HDPE is one of a type of plastics that can be molded again and again.

Plastic additives

Organic or inorganic compound additives can be blended into most plastics. The average content of additives is a few percent. Many of the controversies associated with plastics actually relate to the additives, some particularly toxic. Typical additives includes stabilizers, fillers, plasticizers, colorants etc.[20-22]

Materials and methods

Materials

HDPE plastic waste, Calcium Carbonate, glass fiber, metal cooking pots, clay cooking pots, metal mold etc. were used for cutting board development. The authors used three metal molds having a dimension of 43cm × 27cm × 2cm, 35cm × 22cm × 1cm, 34 × 24 × 1.5cm (Length × Width × Height).

Methods of data collection

Primary and secondary data gathering techniques were applied simultaneously. Primary data were collected through interviews and field observations. As well, secondary data was gathered by reviewing different literature. The authors selected Bahir Dar city purposively for amount of plastic waste estimated, due to the rapid population growth and increasing amount of plastic waste generation in the city.

Research design and method

As there is no international consensus on the method of solid waste characterization, there is a variety of methods used to assess household waste composition. Some methods are standardized, while others are used in one or a few studies. Many methods have been developed to keep track of the waste production within a specific country. While most methods physically sample the waste produced within a certain timeframe from a certain portion of the whole assessed population, some methods are based on product flow and Life Cycle Assessments to predict and estimate the waste that will be produced.[23]

Based on Dahlén, Lisa & Lagerkvist,[23] material flow analyses is made using physical methods, which mainly include sampling of collected HDPE plastic waste and sold plastic through trucks by plastic shredding SME's found in Bahir Dar city. Mbande[24] suggested that interviews are also an appropriate approach for collecting estimated waste quantities in developing countries where municipal solid waste is not collected to the same degree. Thus, plastic shredding and recycling SME's owners found in Bahir Dar city were interviewed to estimate the amount of waste HDPE plastic in the city.

Method of HDPE plastic waste amount estimation

Bahir Dar is the former capital of Gojjam province and the current capital of the Amhara National Regional State (ANRS) located in north-western Ethiopia. The city has more than 324,000 inhabitants including rural areas in 2015. Bahir Dar city is one of the big cities in Ethiopia that generate about 50.19 tons of municipal biomass solid waste per day. The city has prepared a report on solid waste characterization and quantification. As indicated in Table I, the report confirmed that the composition & generation rate of the waste in tonne per day.[25, 26]

The total wastes generated from all sectors were 98.8 tonnes per day and it shows that the residential areas are the primary generators of wastes.[26, 27] Thus, utilizing the municipal solid waste as potential raw materials for recycling and reuses are the most promising methods to overcome the current challenges. Utilization of plastic wastes for different product has environmental and ecological advantages.

Cutting board can be made from different materials including plastics (PVC, HDPE, etc.), wood, glass, etc. The authors mainly

Table I

Composition & generation rate of the waste at Bahir Dar city

S/n	Material	tonne/day
1	Commercial	24.2
2	Institutional	17
3	Street sweeping	3.56

Figure 1. Shredded HDPE plastic waste

focused to develop a cutting board from HDPE code-2 plastic waste, because recycling HDPE is considered eco-friendly, it is the easiest plastic to recycle and commonly used to produce commercial products such as food and water related containers. Consequently, shredded HDPE waste plastic is easily available in Bahir Dar city. Based on Abdalqader[28] and Saidan,[29] the authors used manual assessment method of plastic waste estimation, in order to predict and estimate the minimum amount of HDPE plastic waste generated in Bahir Dar city.

The assessment mainly based on investigating HDPE-code 2 type of plastic waste, when flowing out from HDPE waste plastic shredding SME's at Bahir Dar city. For HDPE-Code 2 plastic, interviews were conducted with shredding SME's owners living in Bahir Dar city. The selected SME's owners are engaged in shredding HDPE and PP waste plastics and sell it for plastic recyclers from Bahir Dar nearby cities and Addis Ababa. Most of waste plastic shredding SME owners in Bahir Dar city were interviewed. Also, when one plastic waste shredding SME owner was found, they could often name others and gave contact information. Accordingly, laborers working in plastic shredding small and medium enterprises were asked some questions related to plastic waste shredding.

Based on interviews and observations, currently in Bahir Dar city there are more than 13 plastic waste collectors and 10 plastic waste shredding SME's. During the field work, 10 plastic waste shredding SME's owners were interviewed about prices and amounts of the HDPE shredded plastic they produce and sell for their customers.

The plastic collectors gather plastic waste from different sources, such as household, private sales, government organizations and landfill. Most of the shredders are engaged in shredding of HDPE code-2 plastic waste including yellow edible oil bottles, green water containers (jerrycans), milk bottles, detergent bottles, etc. The shredders also produce (chopping) PP (polypropylene) plastic items including plastic cloth washing basins, plastic bags etc, but the source and amounts this type of plastic (PP) waste was not assessed.

The shredders are purchasing HDPE type (code -2) plastic waste of 1Kg with $0.51 from plastic collectors in the area. The waste plastic material will be sorted and washed. Then, the plastic will be shredded or chopped by plastic shredding machine into small pieces. The shredded plastic is then sold to waste plastic recycling SME's in Bahir Dar, nearby city and Addis Ababa. Currently, the plastic shredding SME's are selling shredded plastic between $0.77/Kg-$1.02/Kg. Based on observations and interviews made with waste plastic shredding SME owners in Bahir Dar city. The shredding SME produce around 60 Kg – 100 Kg of shredded HDPE plastics per day. Most of the shredders do not have recorded documents about the quantity of shredded plastic they produced and sell, the estimated amount was derived during interviews with shredding SME owners. By basing on a shredded HDPE waste estimate, it can be used as a benchmark (point of reference) to what is the probable minimum available HDPE shredded plastic in the area.

As shown in Figure 1, one shredding SME will produce an average of 480 Kg shredded plastic (i.e. 80Kg/day * 6days/week) and 10 shredding SME will produce an average of 4800Kg of plastic waste/week and 1,228,800 Kg/Year (i.e. 240 working days per day). These estimates will be used in this analysis and do not indicate the total amount of HDPE plastic waste generated in Bahir Dar city, because different nearby cities plastic collectors and shredders are purchasing waste plastic bottles. The estimation is used to indicate the minimum amount and availability (feasibility) of HDPE plastic waste in the city.

Currently, the shredders are selling shredded plastic between $0.77/Kg-$1.02/Kg (i.e. an average of $0.89/Kg) to recycling companies and SME's. Most of the shredders were loading (selling) the shredded plastic in ISUZU FSR truck minimum once per week for plastic recycling customers coming from Bahir Dar and nearby city. The authors bought yellow color and green color HDPE-Code-2 shredded plastic waste with a cost of $0.77/Kg from "Adane waste plastic shredding SME (company)" which is located around Kebele 12 in Bahir Dar city.

Figure 2. Visiting Amhara Pipe Factory (Bahir Dar city, 2020)

Cutting board development procedures

Physical properties of original plastic products, additives used in the plastic and the washing regime used in recycling are all important to the expected behavior and applicability of the products.[10] As shown in Figure 2, the authors visited Amhara pipe factory found in Bahir Dar city and they made overview of the company's plastic production unit. The authors understand how plastic melting takes place and the process of plastic molding. Currently, the factory is using different input materials including LPDE, HDPE, PVC, $CaCO_3$, Master batch (*plastics coloring material)* and different additives for production of PVC Pipes, HDPE Pipes, screen and casing pipes, flexible hose, geo-membrane sheet, green house film.

The authors initially bought shredded HDPE waste plastic and carried out washing the plastic pellets with water and soap in order to remove impurities such as oils. The plastic pellets mixed with $CaCO_3$ (filler) and glass fiber. The mixture melted and poured into cutting board mold and pressure applied before it is left to stand for cooling.

Cutting board development

As shown in the Table II, the authors used shredded HDPE waste, glass fiber in order to increase the strength of cutting board and $CaCO_3$ as a filler[30]

Cutting Board development trial 1:

In order to develop a cutting board, melting of the shredded and pouring the melt in to a metal mold is necessary. The authors mixed 2Kg of Shredded HDPE plastic waste, 100g of glass fiber and 200g of $CaCO_3$ and melted the mixture using 5L metal cooking pot for 3.5 hours using a household electrical stove having120°C heating power as shown in Figure 3.

During melting, the cooking pot was closed in order to increase the temperature and protect the melt from contamination. Then, the melt was poured into a mold, but the molded board showed irregularity in surface texture and dimensions due high melt viscosity (thick melt).

Table II

Material used for cutting board development

S/n	Material	Weight	Remark
1	Shredded HDPE plastic waste	2Kg	
2	Glass fiber	100g	5% weight of Shredded HDPE
3	$CaCO_3$ (Filler)	200g	10% weight of Shredded HDPE
	Total weight	2.3 Kg	

Figure 3. Melting Shredded HDPE waste plastic using metal pot by electrical stove and molded cutting board

Figure 4. Melting Shredded HDPE waste plastic using metal pot by wood fire and plastic, and molded cutting board

Here the authors understand that the viscosity of the melt should be less (thinner) and the electrical stove used is not fast to melt the mixture, because the stove that used for melting has 120°C heating power. HDPE has melting temperature between 120°C to 180°C.[31] Based on this, the authors decided to use another melting method or heat source, which is wood fire.

Cutting board development trial 2:

The authors mixed 2Kg of Shredded HDPE, 100g of glass fiber and 200g of $CaCO_3$ and melted the mixture using 5L metal cooking pot using wood fire with manual blowing for 2 hours as shown in Figure 4. Again, the melt was poured into a mold and the mold cooled.

The authors observed that, the second molding trial was better than the first molding trial, but the mold texture requires improvement and the melting time needs to be reduced. The authors decided to use charcoal fire with blowing fan to increase the melting temperature and to reduce melting time.

Cutting board development trial 3:

The authors mixed 2Kg of shredded HDPE, 100g of glass fiber and 200g of $CaCO_3$ and melted the mixture using 5L metal cooking pot using charcoal stove with fire blowing fan for 30 minutes as shown in Figure 5. The viscosity of the melt decreased (thinner) from the first and second melting trials (visual identification). Then, the melt was poured into a mold and cooled.

The molded board showed better surface texture than the second molding trial, but as shown in Figure 5, the metal cooking pot failed (pierced) in the bottom due high amount of heat by charcoal stove with fire blowing fan. The authors understood that the charcoal stove with fire blowing fan has high heat and metal cooking pot has less

Figure 5. Melting Shredded HDPE waste plastic using metal pot by charcoal stove with fire blowing fan, molded cutting board and failed pot

Figure 6. Melting Shredded HDPE waste plastic using clay pot by charcoal stove with fire blowing fan, molded cutting board

resistance for the heat. Then the authors decided to use clay cooking pot for melting.

Cutting board development trial 4:

The authors mixed 2Kg of Shredded HDPE, 100g of glass fiber and 200g of $CaCO_3$ and melted the mixture using 5L clay cooking pot using charcoal stove with fire blowing fan for 30 minutes as shown in Figure 6. The viscosity of the melt decreased (thin) from the first melting trial (visual identification). Then, the melt was poured into a mold and cooled. The molded board showed better surface texture than the first, second and third molding trial. The clay pot shows good resistance for charcoal heat with blowing fan and better surface molded board was made.

Results and discussion

Amount of input mold material and output developed mold weight analysis

In order to get the difference between shredded plastic input material and molded board weight difference, the authors measured the molds weight and got 1.95 Kg, 1.84Kg, 1.8Kg and 1.75 Kg for mold trial 1, 2, 3, and 4 respectively. The average mold weight was1.83 Kg.

The above Table III indicate that, during molding an average of 0.47 Kg material input weight loss is observed and the average weight loss is 20.43%. This indicate that, from 1Kg of molding input material, around 200 gram will be lost during molding process.

Table III

Amount of input mold material and output mold weight

S/n	Input Material	Input material weight	Output mold weight	Percentage of weight loss
1	Shredded HDPE plastic	2Kg		
2	Glass fiber	100g	1.83Kg	20.43%
3	$CaCO_3$ (Filler)	200g		
	Total weight	2.3 Kg		

Table IV

Developed cutting board cost analysis

S/n	Material (Task)	Cost/Kg ($)	Input material cost ($)	Remark
1	Shredded HDPE plastic (2Kg)	$0.77/Kg	$1.53	-
2	Washing	-	$0.128	-
3	Melting cost	-	$0.77	-
4	Glass fiber	$5.12/Kg	$1.53	100g Glass fiber used
5	$CaCO_3$ (Filler)	$1.53/Kg	$0.256	200g $CaCO_3$ used (10% weight of HDPE)
6	Metal mold	-	$0.512	
	Total cost		$4.726	Developed cutting material weight was 2.3 Kg and output mold was 1.83Kg (20% weight loss)

Figure 7. Cutting board sample preparation

Cost analysis

Cost comparison of cutting board in the market with the developed cutting board was made. The authors bought a white plastic cutting board for $16.60, the board having a dimension of 60 × 40 × 1.5 cm (L × W × H). The board weight was 3Kg. In order to get the cost of the board per Kg (value to weight ratio), the cost of the board divided by the weight of board and yielded$5.53/Kg.

As shown in the Table IV, the total cost for input cutting board material (2.3Kg) is $4.73, but the average output molded cutting board weight is 1.83Kg, the weight reduced due to evaporation during melting. In order to get the cost of the board per Kg (value to weight ratio), the cost of the board was divided by the weight of board yielding $2.58/Kg (i.e. $4.73/1.83Kg).

The cost for cutting boards in the market is $5.53/Kg and the cost to produce new cutting board is $2.58/Kg. This indicate that, the new cutting board cost is very cheap compared to cutting board in the market. However, the market cutting board has better quality than the new cutting board.

The financial analysis has only been used to consider the feasibility of recycling HDPE plastic waste for cutting board development. The research will initiate the plastic making industries to produce cutting board from plastic waste material rather than using virgin HDPE plastic.

Cutting board physical properties testing

The developed cutting board was tested for both compression test and hardness test. Cutting board which is available in the market used as a standard for testing and as shown in Figure 7, a testing sample was prepared.

Compression test for cutting board purchased from market (standard)

As shown in Figure 8, compression test for cutting board purchased from market was performed using Universal compression testing machine found at Mechanical and Industrial Engineering Faculty, Bahir Dar University.

Figure 8. Compression test for standard cutting board (market)

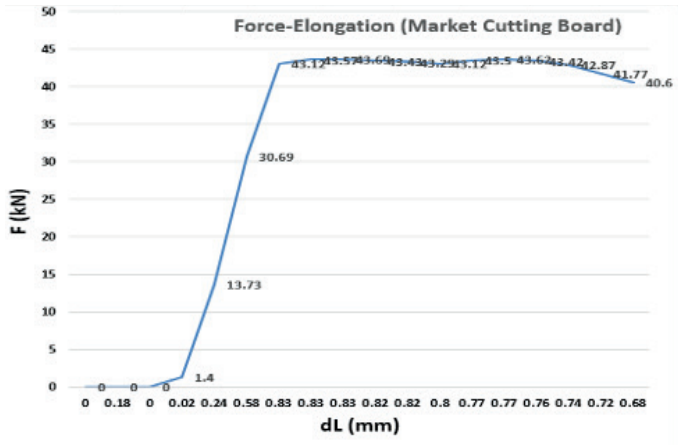
Compression test result for cutting board purchased from market:

Market cutting Board Material: Rigid HDPE - Initial measurement Length: 14 cm; Specimen diameter: 80 mm

Figure 9 shows the compression test result of standard cutting board (market). In the force elongation, when 43.12 kN applied the sample deform about 0.80 mm and when 43.69 kN (highest load) applied the sample deform about 0.83 mm. Based on in the range of 43.12-43.69 kN, the sample deforms in the range of 0.80-0.83 mm.

Compression test for developed cutting board

Compression test for the developed cutting board was performed in order to compare the result with purchased cutting board compression test result. As shown in Figure 10, compression test for developed board was performed using Universal compression testing machine found at Faculty of Mechanical and Industrial Engineering, Bahir Dar University.



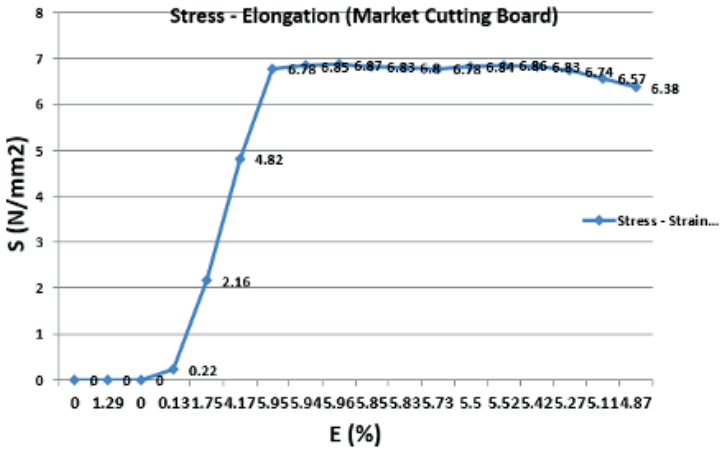


Figure 9. Compression test result for standard cutting board (market)

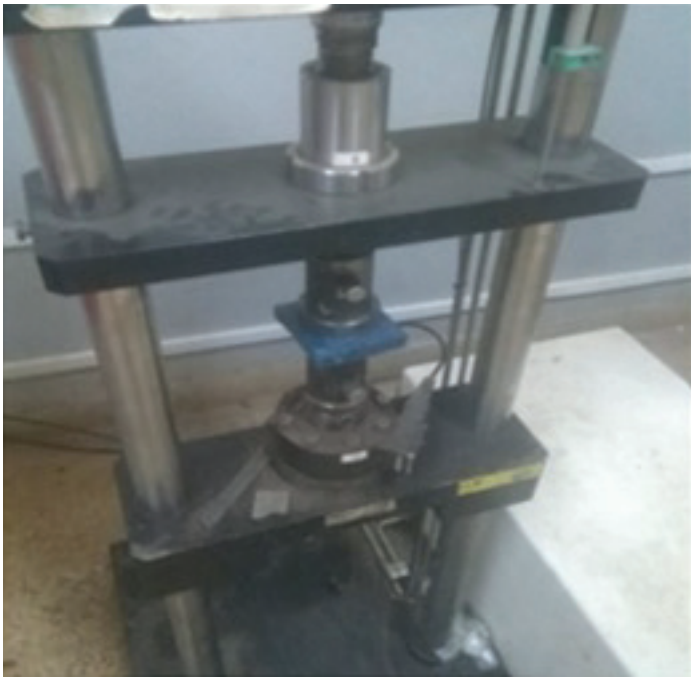


Figure 10. Developed cutting board compression test.

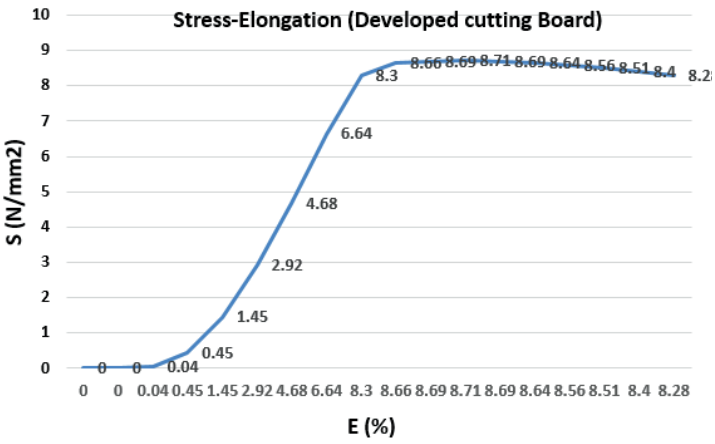
Compression test result for developed cutting board:

Developed cutting Board Material: HDPE; Initial measurement Length: 14 cm; Specimen diameter: 80 mm.

Figure 11 shows the compression test result of developed cutting board. In the force-elongation test result, when 43.04 F (kN) applied the sample deform about 0.85 dL (mm) and when 43.76 F (kN) (highest load) applied the sample deform about 0.87 dL (mm). Based on, in the range of 43.04-43.76 F (kN), the new cutting board sample deform in the range of 0.85-0.87 dL(mm). This indicate that, the developed cutting board has related compression strength with the standard cutting board (market) sample which is 0.80-0.83 dL (mm) in the range of 43.12-43.69 F (kN).

Hardness Test

Rockwell hardness testing machine was used for Hardness test[32] and based on Rockwell hardness scale, scale L No. 10, 60Kg load and ¼" ball indenter is used for both developed and market cutting board hardness testing. As shown in Figure 12, Hardness test was performed using Rockwell hardness tester found at Faculty of Mechanical and Industrial Engineering, Bahir Dar University. Each test trail done for 30 seconds.



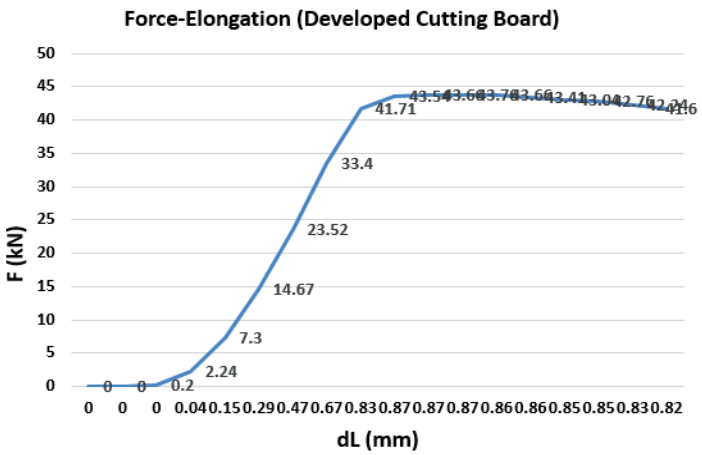


Figure 11. Developed cutting board compression Test

Table V

Hardness Test for standard cutting board (market) and developed cutting board

Test trial	Standard cutting board (market) hardness Test result (HRB)	Developed cutting board hardness Test result (HRB)
Test trial 1	47	80
Test trial 2	42	75
Test trial 3	53	68
Test trial 4	47	55
Test trial 5	55	60
Average Test result	48.8	55.6

Table V shows, the market cutting board average Hardness Test result is 48.8 and the developed cutting board average hardness test result is 55.6. This indicate that, the developed cutting board hardness test result approached to the market cutting board hardness test result. However, the market cutting board has better has better resistance to indentation. Based on these results, it is required to increase the compactness of the developed cutting board.

Conclusion

It is known that plastic waste is the main reason for pollution in the world, because plastic material takes long time to decompose. Plastic recycling is a good option to protect the environment. Thus, the authors developed a cutting board from HDPE plastic waste. The developed cutting board showed relatively lower hardness and compression test result when compared with HDPE cutting board in the market. Developing cutting board from HDPE plastic waste is cheaper and recycling has a good impact in the environment. However, the developed cutting board showed some pores in the surface which reduced the quality of the board. The authors assumed that the reason for the pores in the board will be due to moisture absorbance during manual melting and it is difficult to regulate the amount of charcoal heat (temperature) during manual melting.

The plastic flow analyses indicated the minimum amount of shredded HDPE plastic waste in Bahir Dar city. The minimum HDPE shredded plastic waste amount produced in the city was estimated to be around 1,228,800 Kg/year. Most of the shredded plastic sold to recycling SME's is found in Addis Ababa. This indicate that, Bahir Dar has a good source for HDPE shredded plastic waste and a good opportunity for plastic recyclers engaged in the area and also opportunities for new investors for plastic recycling in the area.

Recommendation

Manual melting at home is a tedious task and it not feasible for mass recycling/production. During Amhara plastic factory visit by authors, melting HDPE plastic by machine has no bad smell. However, during manual HDPE plastic waste melting by authors,

Figure 12. Market cutting board and developed cutting board hardness test

the melt had a bad smell and it is not good for human health. The authors recommend that, melting HDPE plastic waste using plastic melting machine is preferable.

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