Effect of Change in Material and Production Process on Cycle Time, Production Rate, Cost and Impact Strength of Plastic Product

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Abstract: Effect of material change of plastic product is investigated in this research paper. The parameter observed are waste recycle, impact property of product, aesthetic look, cycle time, production rate and cost of product. In this study it was found that by changing the material of product from thermoset plastic to thermoplast plastic and production process from compression molding to injection molding, the product becomes eco friendly because thermoplast material is recyclable. It was also found that impact strength and production rate/hour was also improved due to reduction in cycle time. The aesthetic look : smoothness of surface and glossy look of the product was become better and long lasting. And finally the cost of product was reduced tremendously. The research was carried out in a small scale industry with a case study of ball knob of machine tool handle lever.

Key words – Ball Knob, Bakelite, Nylon-6, Compression Molding, Injection Molding

I. Introduction

Today plastic is used in our life, from home appliances to industrial goods. Plastic product manufacturing industries are suffering tremendous pressure for improving quality of product as well as reducing the cost of the product. Recycling of plastic waste is also big problem for the environment. Government policies become stricter day by day. In such condition plastic industry has to change the material of the product and manufacturing process according to it. So many plastic products are unnecessary made from thermoset plastic which is non recyclable. The plastic product which has not to work under application of heat can be converted into thermoplast plastic which is recyclable.

Compression molding – In this method the Bakelite, in the form of powder, converted into disc, is dried by heating and then further heated to near the curing temperature; this heated disc is loaded directly into the mold cavity. The temperature of the mold cavity is held at 250°C–300 °C, depending on the material. The mold is then partially closed, and the plastic, which is liquefied by the heat and the exerted pressure, flows into the recess of the mold. At this stage the mold is fully closed, and the flow and cure of the plastic are complete. Finally, the mold is opened, and the completely cured molded part is ejected. This method generally used for thermoset plastic material. The process is shown in fig-1 [i][ii].
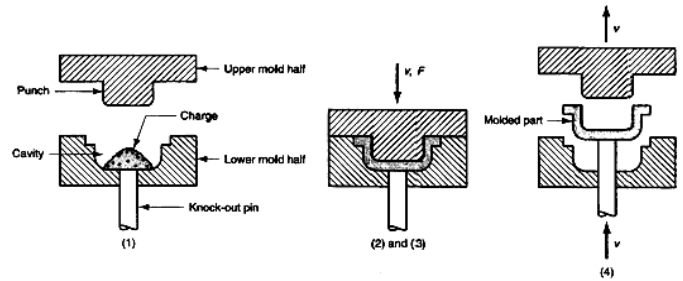

Fig.1 compression molding[ii]

Injection molding – It is based on the ability of nylon-6 materials to be softened and melt by heating and to harden when cooled. The process thus consists essentially of softening the nylon-6 material in a heated cylinder and injecting it under pressure into the mold cavity, where it hardens by cooling. Each step is carried out in a separate zone of the same apparatus in the cyclic operation. A diagram of a typical injection-molding machine is shown in Fig. 2[ii]. Granular material (the plastic resin) falls from the hopper into the barrel when the plunger is withdrawn. The plunger then pushes the material into the heating zone, where it is heated and softened (plasticized or plasticated). Rapid heating takes place due to spreading of the polymer into a thin film around a torpedo. The already molten polymer displaced by this new material is pushed forward through the nozzle, which is in intimate contact with the mold. The molten polymer flows through the sprue opening in the die, down the runner, past the gate, and into the mold cavity. The mold is held tightly closed by the clamping action of the press platen. The molten polymer is thus forced into all parts of the mold cavities, giving a perfect reproduction of the mold. The material in the mold must be cooled under pressure below melting point temperature before the mold is opened and the molded part is ejected. The plunger is then withdrawn, a fresh charge of material drops down, the mold is closed under a locking force, and the entire cycle is repeated.[i][ii].
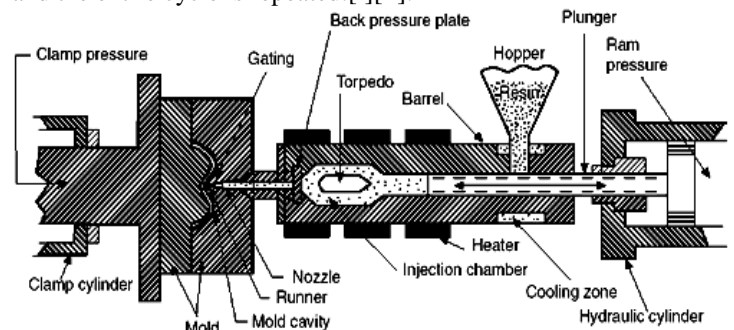

Fig-2 Injection molding process[ii]

Productivity – as per ILO productivity can be defined as ratio of aggregate output to aggregate input. According to Peter Drucker, "Productivity means a balance between all factors of production that will give the maximum output with the smallest effort".[iv][v] [vi]

$$\text{Material Productivity} = \frac{\text{Number of unit produced} \times 100}{\text{Cost of material}}$$

$$\text{Labour Productivity} = \frac{\text{Aggregate output} \times 100}{\text{Total man hours required}}$$

$$\text{Machine Productivity} = \frac{\text{Output} \times 100}{\text{Actual machine hours utilized}}$$

$$\text{Aggregate productivity} = \frac{\text{Output} \times 100}{\text{Land} + \text{Labour} + \text{Material} + \text{Capital} + \text{other input}}$$

II. Literature Review

A. George Staniulis, AGS Technology, Inc. & Schaumburg, III has focused on automobile companies to lower their costs. He suggested that productivity improvement and reuse of scrap after conditioning and modification of process are only the solution. He found that the raw material saving is possible upto 50% [vii]. James Henderson, Aaron K. Ball, James Z. Zhang have focused on optimizing the parameter of injection molding process. They optimized the process parameter like cooling time, back pressure and cycle time for each part. In this paper it was proved that only significant parameter was cooling time and it was only parameter that had major effect overall cycle time. By manipulating the four temperatures in the heating bands could decrease the cooling time which would decrease the overall cycle time. [viii]. Adekunle A. Fagade and David O. Kazmer have focused on early cost estimation of by using CAD design. [ix]. Mika Hunnula and Petri Suomala have focused on finding out which are the most important obstacles to productivity improvement in small and medium size manufacturing companies in Pirkanma, a province in southern Finland.[x]. M.E. Sheriver, K.A.Beiter and K.Ishii in which they have focused on change in properties of recycled thermoplastics [xi]. They found that

1. Mw – molecular weight decreases slightly over ten generations of processing. Blending the tenth generation regrind with virgin material does not significantly alter the Mw of the regrind.
2. The melt index for polycarbonate is directly proportional to the number of regrind generations, i.e. viscosity decreases as the material degrades. Blending virgin material with tenth generation regrind decreases the MI i.e. viscosity increases.
3. Polycarbonate mechanical performance did not significantly degrade over the ten generations of processing. Izod impact strength increases with increasing virgin material percentage.
4. Yellowness and darkness increase as generation number increases.

III. Materials & Methodology
Product – Machine tool lever ball knob shown in Fig.-3(A)
Volume – 22.12 cm^3
Bakelite ball knob manufacturing by compression molding in industry was observed and different parameters noted in the observation table-2. Then for manufacturing same product by injection molding, die was designed shown in FIG.-3(B). The knob of same dimension and volume was made by manual injection molding and different parameters were recorded in observation table-2. Material used for both knobs were compared in table-1[iii]. The cycle time is calculated by application of time study method of actual cycle time recorded of different workers[iv][v] [vi].
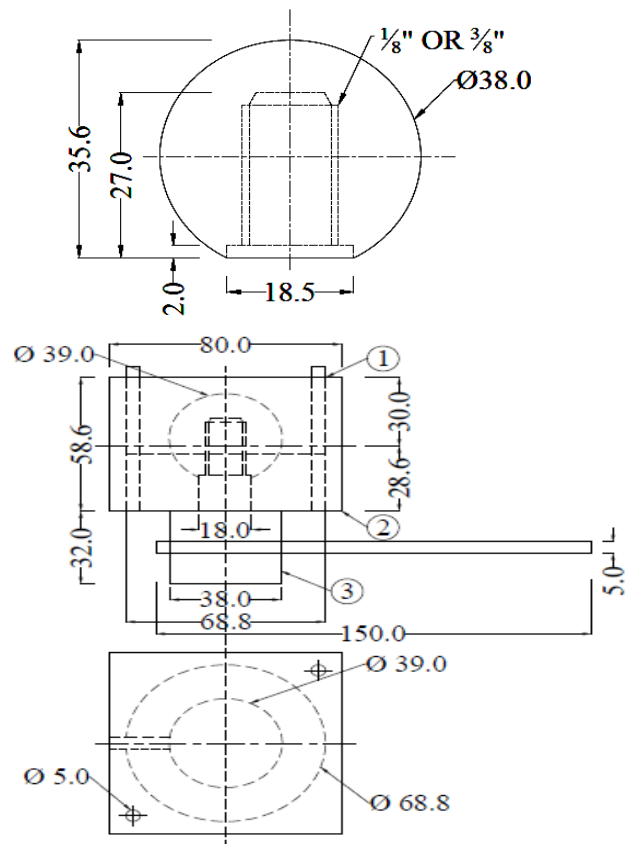
All dimensions are in mm
Fig-3 (A) Knob sketch (B) Injection molding die
Table -1 MATERIAL COMPARISION [3]

Sr. No.	Property	Bakelite	Nylon-6
1	Molding Qualities	Good	Excellent
2	Relative Density (gm / cm^3)	1.25-1.30	1.13-1.15
3	Tensile Strength, Mpa (Psi)	48-55 (7000-8000)	62-82 (9000-12000)
4	Impact Strength Izod J/mm	0.01-0.018	0.05 -- 0.1
5	Hardness Rockwell	R 124-R 128	R 108-R 120
6	Machining Qualities	Fair to Good	Excellent
7	Melting point	240^0 C	220^0 C

Impact test of knob – After manufacturing impact test of both knobs were performed to find impact strength. The specimen prepared and machine used for impact test is shown in fig.4(A) and 4(B).

FIG. 4 IMPACT TEST OF KNOBS
(A) Test specimen   (B) Impact testing machine

Procedure for impact test
1. With the pendulum locked in the state of rest position, grip the test specimen firmly in vice of the impact testing machine.
2. Locate and lock the striking hammer in its topmost striking position.
3. With the help of trigger, the pendulum is released so that the pendulum while striking will knock the specimen and break it.
4. The used energy used to break the specimen was noted from graduated scale of machine into table-3. The difference between initial and final readings represents the residual energy in the pendulum.

IV. Results & Tables

Table -2 OBSERVATION TABLE

Sr. No.	Parameter	Existing Process	Modified Process
1	Material of knob	Phenolics (Bakelite)	Polyamide – 6 (Nylon – 6)
2	Density (gm / cm^3)	1.3	1.13
3	Manufacturing Process	Compression Molding	Injection Molding
4	Weight of knob	29 gms	25 gms
5	Material cost Rs/kg	45	50
6	Rejection rate	5 %	8 %
7	Flash loss & scrap	6.7 gm /knob	NIL due to Recyclable
8	Material required / knob	35.7 gms	25 gms
9	Material cost Rs/knob	1.6065	1.25
10	Die cost for 100000 pieces	Rs 30000	12000
11	Molding time (Sec.)	165	30
12	Down time (Sec.)	50	60
13	Cycle time (Sec.)	215	90
14	Electricity consumption	3.5 KWH	2.1 KWH
15	Rate of electricity	Rs. 8.5 / KWH	Rs. 8.5 / KWH
16	Electricity cost Rs / knob	1.7767	0.4462
17	Labor cost @ Rs 200 / 8 hr. (Rs/knob)	1.4930	0.6250
18	Finishing cost (Rs/knob)	0.01594	NIL
19	Total cost (Rs/Knob)	5.19214	2.3212
20	No. of pieces produced / Hr	16.74	40

Table-3 OBSERVATION TABLE OF IMPACT TEST

Sr. No	Material	Initial impact energy (Joule)	Energy used in air & machine friction (Joule)	Energy used to break the specimen (Joule)	Energy absorbed by specimen (Joule)	Residual Energy after impact (Joule)
1	Bakelite	17	0.675	1.55	0.875	15.45
2	Nylon-6	17	0.675	4.1	3.425	12.9
3	Steel	17	0.675	5.8	5.125	11.2

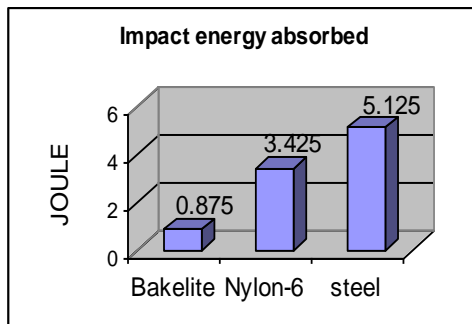Different parameters observed from the experiment are represented in Fig-5.
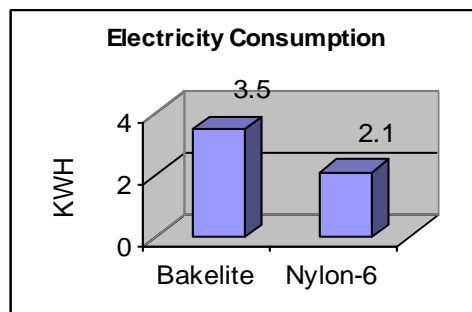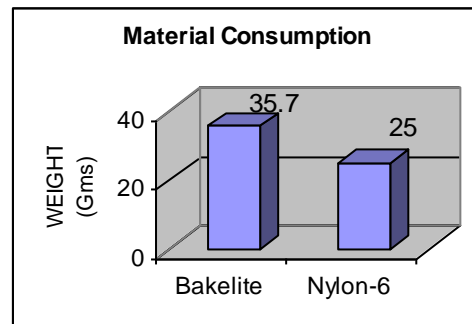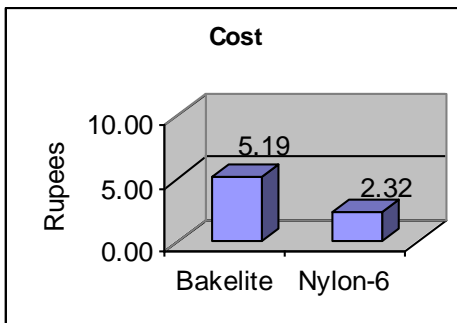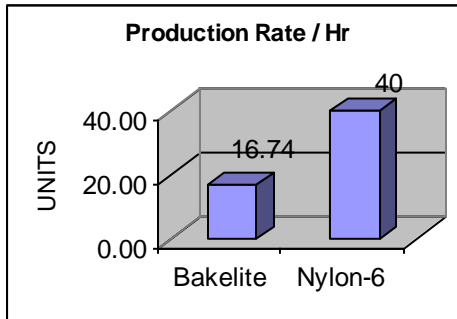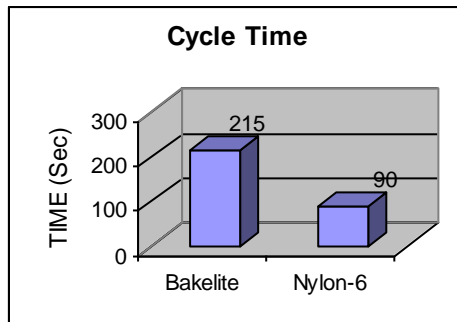
Fig-5 Result analysis

V. Conclusion

From observation tables and fig-5 we can concluded following main points of research work :

1. By changing product material from Bakelite to Nylon-6, material consumption per knob was reduced from 35.7 gms to 25 gms. So 30% plastic raw material was saved. By using Nylon-6 material and in injection molding process knob can be produced with zero scrap because all the wastage can be recycled and reused due to a thermoplast material.

2. Weight of knob can be reduced from 29 gms to 25 gms due to less density of Nylon-6 material.

3. In injection molding electricity consumption per hour is 3 KWH which is less than 3.5 KWH in compression molding process. During the manufacturing it was not necessary to continuously heat the raw material in barrel, it was equipped with thermostat which remained 30% time off. Hence net electricity consumption was reduced upto 40% compare to compression molding.

4. Cycle time was reduced from 215 sec/knob to 90 sec/knob. Due to this production rate per hour was increased from 16.74 knobs/hour of Bakelite knob to 40 knobs per hour of Nylon-6. Hence productivity was increased by 138.94 %. Material productivity is increased from 62.24 % to 80%.

5. Production cost of Nylon-6 knob was reduced upto Rs 2.87/knob. So production cost was reduced by 55.29%.

6. It was observed in impact test that impact strength of knob was improved by 3.91 times. That means less damage of machine tool lever handle knob in operation.

7. Surface finish of Nylon-6 knob was glossy and this glossy look will remain long lasting. Unlike Bakelite knob no additional surface finish process was required.

8. Bakelite is a thermoset material, so once melted and hardened it is not possible to melt it again in case of wastage or damage of knob, it is having the best application where heating of product is done in use. But in most of application like machine lever handle knob heat is not applied in used and damage of knob in use is another big problem. Hence unnecessary non recyclable wastage is produced. This can be reduced by changing the material of ball knob by Nylon-6 which is having higher impact strength and easily recyclable.

VI. Future Scope

1. In manual injection molding of machine tool handle lever knob it was found that rejection rate was 8% due to various defect which is higher than 5% of compression molding. The rejection rate can reduced by application of automatic machine.

2. In manual injection molding of handle lever knob the down time was 60 second which is higher than that of 50 sec in compression molding. This can be reduced by application of automatic machine with multi cavity die.

3. This research was carried out in small scale industry with single cavity die and manual injection molding machine. So human element was play vital role. If automation was applied in plastic product manufacturing industry than productivity may further increased and hence cost of product can further decreased.

4. The cost of knob can further reduced by using recycled nylon-6 material.

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