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Design and Mould Flow Analysis of Injection Mould for Luggage Bag Wheel

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ABSTRACT

With the heavy demand in plastic products, plastic industries are growing in a faster rate. Plastic injection moulding begins with mould making and manufacturing of intricate shape with good dimensional accuracy. To meet such requirements it is very important to adopt various advance technologies for the development of injection moulded components. This study deals with Design and Mould Flow Analysis of an automatic plastic injection mould for production of Luggage Bag Wheel. Plastic wheels, commonly used in standard bags, suitcases are manufactured by the injection moulding process all around the world. This wheel is manufactured in three steps. The material used for wheel is Polypropylene (PP) for inner core and Thermoplastic Elastomer - Polyvinyl Chloride (PVC) for the Wheel Tyre. Guide bush is used which acts as a sleeve is made by material Derlyin (Polyacetal). Modelling is done by using Unigraphics (NX6.0). The elements of injection moulding tool are designed and analyzed by Mould Flow Analysis software. A Design of Experiments (DOE) of the moulding process parameters is used to identify key moulding parameters by analysing a multi cavity injection system.

Keywords : Luggage Bag Wheel, Mould, Injection Moulding, Mould Flow Analysis, Unigraphics.

I. INTRODUCTION

The technology of the Tool and Die manufacturing is one of the fastest growing technologies in the world. Injection moulding machine which is used to manufacture small plastic parts, consists of alternate heating and cooling processes in one setup which leads to increase in cycle time for per product.

Contradictory to this, future need is to improve the process to increase productivity, reduce the cycle time in injection moulding. In order to achieve the processing parameters, they commonly follows on experience, hit and trail method due to which this process is not practical for complex models. As new generation designers require more powerful software to analyze and to optimize injection moulding process by manipulating parameters to reduce cycle time. However development of CAD/CAM/CAE technology especially Mould flow Analysis, the number of trails on mould can be reduce with the achievement in product quality. Analyzing and improving component and mould design characteristics, thus can be assistance to improve the reliability and simplicity and reduce the extra cost required for the product production.

This paper is focused on the design development and its mould flow analysis for luggage bag plastic wheels. Luggage bag plastic wheel is manufactured by insert moulding process in three steps. Initially, sleeve is manufactured which is kept as an insert in second step to manufacture the wheel core. The manufactured wheel core is kept as an insert in third step of insert moulding to obtain the final wheel as a product. So, three different mould tool are designed for three parts. Fig. 1.1(a) shows the actual required wheel.

Fig. 1.1(a) Fig. 1.1(b) Fig. 1.1(c)

Figure 1. Initial product of luggage bag wheel

But this design is leading to failure in the product manufacturing during its third stage. Since, more stresses are developed on the inner part of the wheel i.e. wheel core. These excess stress leads to undesired assembly as shown in fig.1.1 (b) and (c). This causes wastage of plastic material and leads to increase in amount of rework to get the desired product. Also, it leads to unbalance of wheel. Hence, work is done to overcome this problem by proposing new design based on some analysis parameters.

A. Abbreviations and Acronyms

t = Rib thickness
h = Rib height
R_i = Intensification ratio
ρ = Density

B. Objective

Objective of this paper is to reduce the stresses on inner part of the wheel during third stage of wheel manufacturing. This is obtained by developing the new wheel design. It includes,
i) To develop new design.
ii) To design feed system like sprue, runner and gate.
iii) Analysis of plastic flow in two plate injection mould.

C. Methodology

This paper will present a practical Component and Tool Design procedure/methodology of an injection mould.
(i) Material Study
(ii) Component Modelling
(iii) CAD for Mould Design
(iv) Mould Flow Analysis
(v) Mould Manufacturing and Practical Analysis

II. LITERATURE REVIEW

H Adithya Bhat, et al [3] had worked on plastic side release buckle which is normally used in standard bags, suitcases, pouches. Gate location is one of the important parameter used for analysis purpose of the buckle using mould flow software. Focus is to determine optimum gate locations for it. The analysis considers identification and improvement of parameters such as fill time, quality, extent of packing and reduced defects and war page. Utilization of the optimized gate locations for the mould lead to reduced production costs, higher quality and enhanced competitive power of mould enterprises.

Madhukumar et al [6] had designed and analyzed mould tool for Air filter box bottom cover by using Poly Propylene talc filled [PPTF] material. In this paper they have done all numeric calculations to predict mould detail dimensions. Designing of mould parts is carried out by using wildfire Pro-E 3.0. Then after assembly 3D models are converted into the 2D drawings for manufacturing process.

Anil Kumar et al [7] had worked on Industrial Helmet its design parameters and its analysis. In the first stage they had designed parametric model by using 3D modeling module in Pro-Engineer software. After that mould flow analysis is carried out on helmet by using plastic advisor which is a module in pro/E. In the second stage, after completion of the mould flow analysis impact analysis was done on industrial helmet by using COSMOS software for the three different materials Nylon 4-6, ABS plastic and Impact ABS plastic each from three different heights 2000mm, 3000mm, 4000mm.In this chapter, it is found that the Nylon 4-6 plastic is good instead of ABS plastic.

Jagannatha Rao M B et al [9] had focused on the analysis of plastic flow in two plate injection mould. Mould flow analysis software is used to perform the analysis of filling, wrap and best gate location. The analysis begins with the origin of the flow channels such as nozzle, sprue, runners, and gates until the cavity is completely filled. The main objectives of their research were to design plastic part, to design feeding system like sprue, runner and gate in two plate injection mould, to set optimum process parameter like injection pressure, speed, temperature and other, analysis plastic flow in two plate injection Mould.

S. Selvaraj et al [17] had worked on design and fabrication of automatic injection moulding of Cam Bush which has electrical applications. The elements of injection moulding tool have been designed, fabricated and assembled. Nylon-66 is used material for cam bush.

III. INNER WHEEL CORE DESIGN AND ITS ANALYSIS

With respect to the objective the work is focused on the development of inner wheel core. Fig. 1.1 implies the maximum deformation occurs at the inner walls. This shows that the inner walls are not stiff to sustain the external pressure applied through the PVC material during third stage of manufacturing. When the normal wall thickness is not stiff enough to stand up to service conditions the part should be strengthened by adding ribs instead of making the solid component. If the rib is too thin it will have to be made deeper to give adequate rigidity and then it may buckle under load. And if it is too thick it will leads to increase in material.

A. Rib Design Calculation

Nominal wall thickness = 4 mm

Rib thickness = Should not be more than 0.4 to 0.75 times nominal wall thickness. $t = 0.5 \times 4 = 2$mm

Using this rib thickness the new inner wheel core is designed called as "New inner wheel core with ribs". Equal rigidity in all direction is obtained by running rib of 2mm thickness and 21mm in height, along and across the part with the angle 60° between two adjacent ribs.

Rib height = Should not be more than 2.4 to 3 times nominal wall thickness. $h = 2.4 \times 4 = 9.6$mm

If rib is too long then it leads to buckling which affects on the strength of the rib. As the total height of the wheel is 21mm, but recommended rib height is 9.6mm hence, two ribs of 9.5mm are selected with 2mm of plate between them. Using this rib thickness and rib height another new inner wheel core is designed, called as "New inner wheel core with ribs and plate. With these both the models are developed in Unigraphics (NX 6.0) and converted to igs format to import it in ANSYS for further analysis. Hence, the comparison is done in between three designs i.e. 1) Old inner wheel core 2) New inner wheel core with ribs and 3) New inner wheel core with ribs and plate, using ANSYS.

B. Analysis by ANSYS

For analysis by ANSYS, the inner core is considered as product and uniform pressure is applied on its outer surface. This applied uniform pressure i.e. material pressure (injection pressure) is calculated by considering intensification ratio(R_i) of machine.

i) Injection Pressure Calculation

Intensification ratio = Injection Pressure/Hydraulic Pressure

Injection pressure = 1800kg/cm^2

Hydraulic pressure = 140 kg/cm^2

R_i = 12.85:1

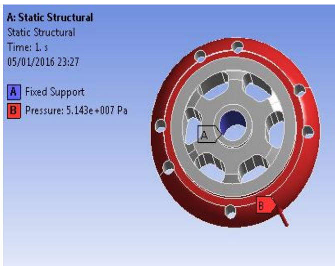
From process sheet for wheel tyre,

Hydraulic Pressure = 40bar

Therefore, Injection pressure = 514.28bar = 51.43MPa

Material Properties considered in ANSYS for Polypropylene are

Density(ρ)	= 0.951g/cm^3
Young's Modulus	= 1390 MPa
Poisson's ratio	= 0.28
Tensile Strength, ultimate	= 28 MPa
Tensile Strength, yield	= 26.6 MPa



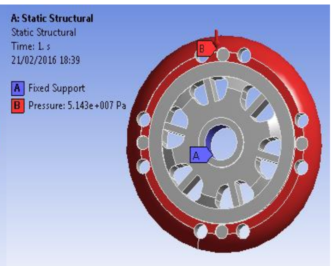


Fig. 3.1(a) Fig. 3.1(b)

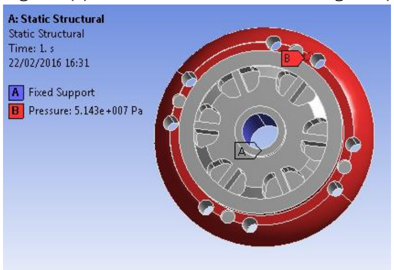
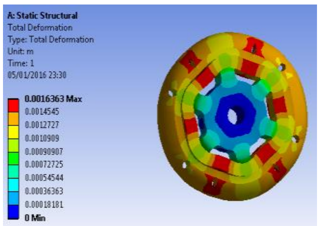


Fig. 3.1(c)

Figure 3.1. Loads and Boundary Conditions for (a) Old wheel inner core (b) New wheel Inner core with ribs (c) New wheel inner core with ribs and plate

- **Structural Analysis for Total Deformation**



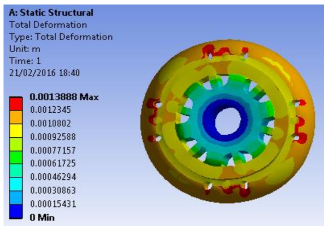


Fig. 3.2(a) Fig. 3.2(b)

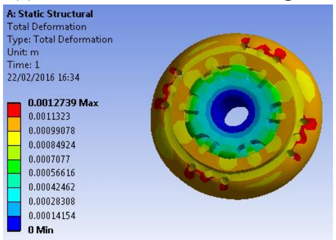


Fig. 3.2(c)

Figure 3.2. Total Deformation for (a) Old wheel inner core (b) New wheel Inner core with ribs (c) New wheel inner core with ribs and plate.

From fig. 3.2 it is seen that the total deformation obtained is least among the three design in case of new inner wheel core with ribs and plate. Hence, it is concluded that this design fullfills the required objective. Mass of the old inner wheel core is 0.03557 kg and mass of new inner wheel core is 0.03807 kg. The difference is of 0.0025 kg i.e. 2.5g. It means using new design of inner wheel core increases 2.5g of material use per inner core.

C. New Mould Design

From the results of ANSYS, UG model of wheel core is used to design the injection mould tool. The shrinkage of PP is applied to wheel core model through the scale body option. Then that model is used to design cavity and core plate. The runner used in old injection mould is half runner which leads to increase in injection time and ultimately the cycle time. Fig.3.3 shows the cavity and core plate for the old injection mould tool for wheel core.

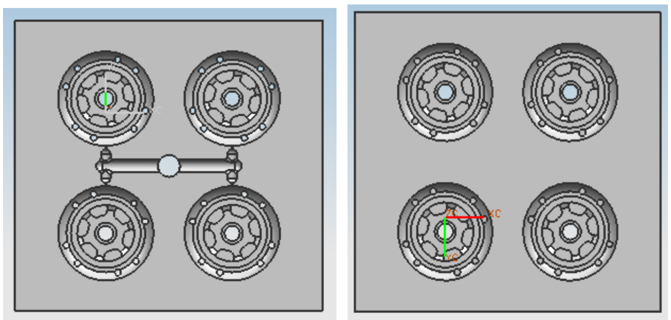


Fig. 3.3(a) Fig. 3.3(b)

Figure 3.3 Old design for wheel core (a) Cavity plate (b) Core plate

The modification is done in runner layout and runner type. For new injection mould tool of wheel core the parting runner is used. And the runner layout is as shown in fig.3.4.

1. Runner Diameter Calculation [17]

$D = (\sqrt{W} \times \sqrt[3]{L}) / 3.5$

L = Length of Runner = 32mm

W = Weight of wheel = 39.23g

Hence, Diameter of runner = 5.597mm

Assumed Diameter = 6mm

Hence, semicircular cross sectional runner is selected.

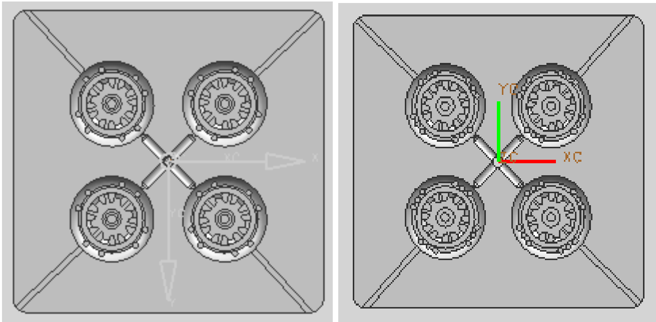


Fig. 3.4(a)

Fig. 3.4(b)

Figure 3.4 New design for wheel core (a) Cavity plate (b) Core plate

2. Air Vents

The cavity space injected by plastic material leads to fill the empty space on the cavity; the air in the cavity will be shifted to another place. The main function of the venting is to release the compressed air, when compressed air is not expelled from the cavity, the plastic flow is inhibited, the result will be formed on a short shot of the product. Hence, the air vents are provided at the positioned opposite to the gate point as shown in fig.3.4, with the width of 4mm and depth of 0.25mm.

3. Cooling Lines

In the old mould the cooling lines were provided in the cavity back plate and in the core housing for fixed half and moving half respectively, which shows that the distance between the cavity and cooling lines is more. Hence, time required for cooling of the molten plastic is more. This leads to increase in cooling time. Fig. 3.5 shows the geometry of old cooling lines.

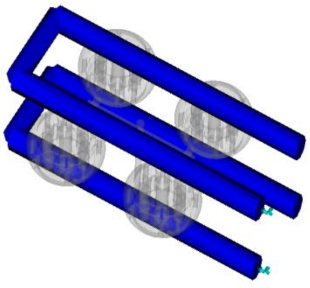


Figure 3.5 Old cooling lines

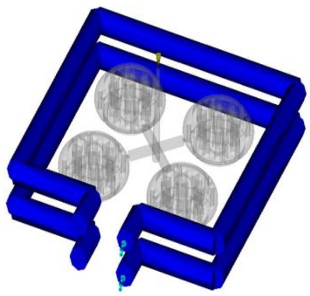


Figure 3.6 New cooling lines

Hence, to compensate with the cooling time, new cooling lines are designed. In new mould the cooling lines are provided in the cavity and core plate itself. Hence, time required to cool the molten plastic is less compared to the old mould cooling lines. Fig. 3.6 shows the geometry of the new cooling lines. Diameter of cooling line is kept same for new and old mould that is 12mm.

D. Mould Flow Analysis Result

In the past there was a risk that flaws in part designs would not be noticed until a mould tool was made. Changes in part and mould design at this stage would be expensive and time consuming.[3] The software will predict potential quality issues in the part such as flow lines, weld lines, deep under cuts, inadequate draft angles, war page and sink marks. This means that part design changes can be made immediately to address these issues with little time and cost. Hence, the field of flow analysis is gaining much importance in injection moulding. The interrelationships between part design and moulding process parameters were analyzed in order to determine the optimum criteria.

Mould flow analysis helps to

1. Visualize the flow path of polymer to identify conditions that could result in surface defects on the part.
2. Reduce or eliminate many production problems and defects by selecting the correct gate location.
3. Identify where defects will occur, and how you can change your design or moulding conditions to reduce or eliminate them.
4. Moldflow helps you to imagine, design and create your entire moulding process using Moldflow Design, Moldflow Adviser and Moldflow Insight software.
5. Verify multi-cavity and family moulds fill at the same time and pressure.[9]

- **Comparison of mould flow result**

Case 1 : Old design old runner

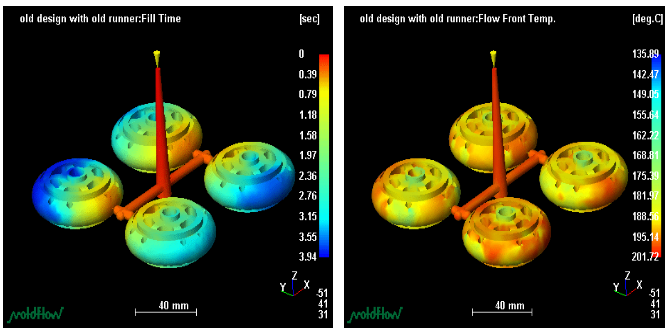


Fig. 3.7(a) Fig. 3.7((b)

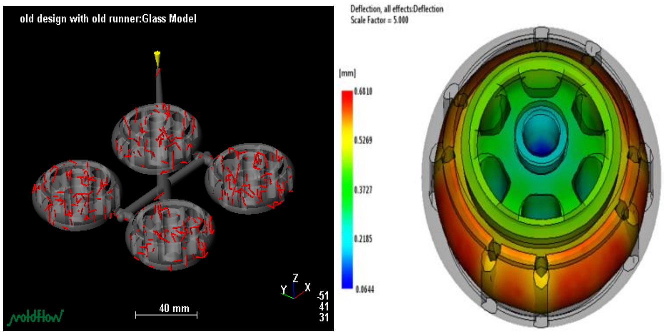


Fig. 3.7(c) Fig. 3.7(d)

Figure 3.7 MFA of old design (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis

Case 2 : Old design new runner

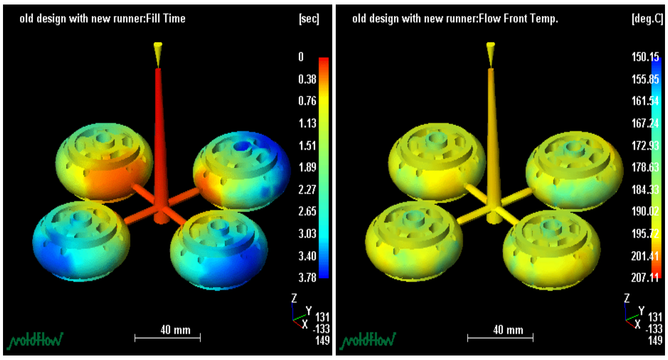


Fig. 3.8(a) Fig. 3.8(b)

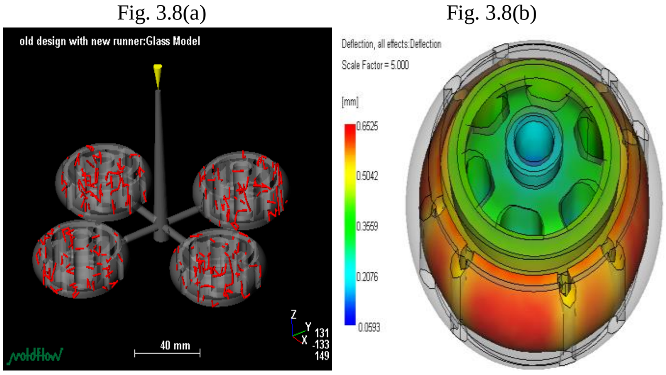


Fig. 3.8(c) Fig. 3.8(d)

Figure 3.8 MFA of old design (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis

Case 3 : New design old runner

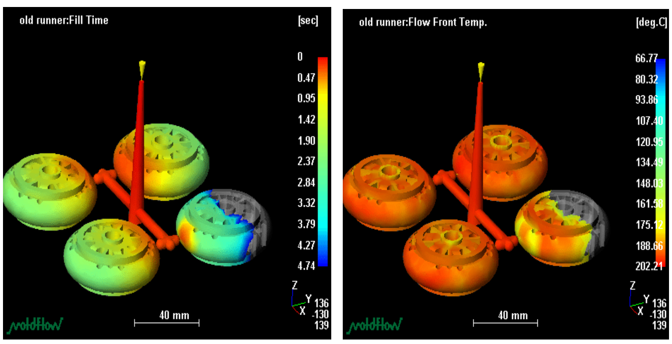


Fig. 3.9(a) Fig. 3.9 (b)

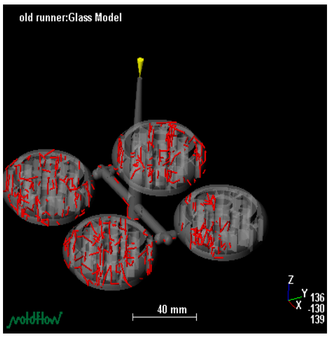


Fig. 3.9 (c)

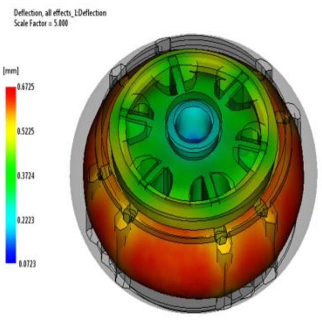


Fig. 3.9 (d)

Figure 3.9 MFA of new design (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis

Case 4 : New design new runner

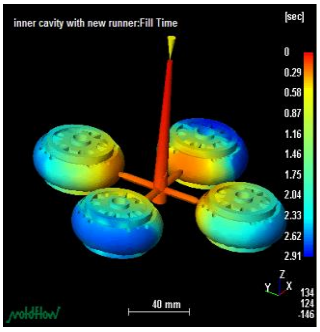


Fig. 3.10(a)

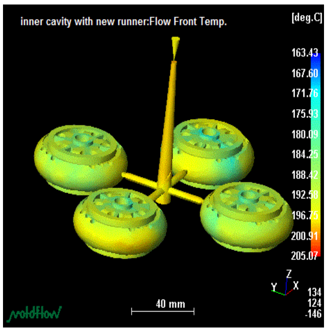


Fig. 3.10(b)

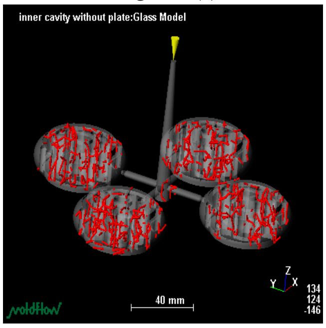


Fig. 3.10(c)

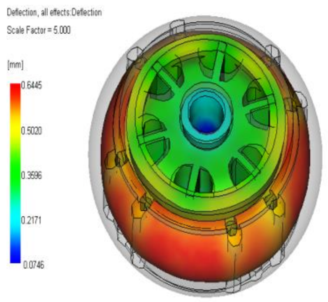


Fig. 3.10(d)

Figure 3.10 MFA of new design (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis

Table 3.1 Results of mould flow analysis

Parameters	Old Design		New Design	
	Old Runner	New Runner	Old Runner	New Runner
Fill Time(s)	3.94	3.78	4.74	2.91
Shot Volume(cm^3)	154.85	153.49	162.79	147.23
Flow front temp(°C)	201.72	207.11	202.21	205.07
Confidence of fill	High	High	Low	High
Air traps	Yes	Yes	Yes	Yes
Warp age in all direction (mm)	0.6810	0.6525	0.6725	0.6445
Sink Marks	1.650	1.650	0.9990	0.9608
Weld Lines	Yes	Yes	Yes	Yes

From the mould flow analysis the new design with new runner showed the best result. Hence, after ANSYS and Mould flow analysis confirmation the new design with new runner was selected.

IV. WHEEL TYRE DESIGN AND ITS ANALYSIS

A. Design of Wheel Tyre Mould

As per above discussion, from the ANSYS and Mould Flow Analysis result, it was founded that by considering the new inner wheel core design there is increase in mass of core, which leads to increase in amount of material required. This will increase the cost per wheel hence, to compensate this required cost; the work is also done on the wheel tyre. The outer diameter of the wheel is been reduced by 4mm. Hence, the wheel tyre, consider for the analysis is of same design with the change in dimension without any change in strength of wheel. Fig. 4.1 shows the wheel tyre.

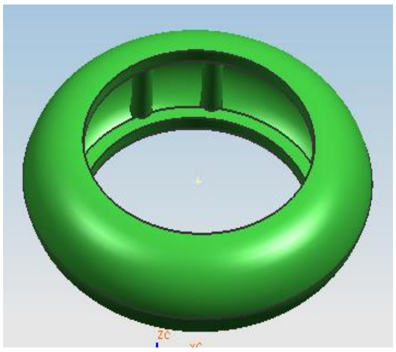


Figure 4.1 New Wheel Tyre

While designing the wheel tyre mould all same factors were consider which were discussed for inner wheel core.

B. Design of Core and Cavity plate of Wheel Tyre Mould

The model shown in fig. 4.1 with 67mm as diameter is used to design the injection mould tool. The shrinkage of PVC is applied to wheel tyre model through the scale body option in UG. Then that model is used to design cavity and core plate. Fig. 4.2 shows the cavity and core plate for the old injection mould tool for wheel core.

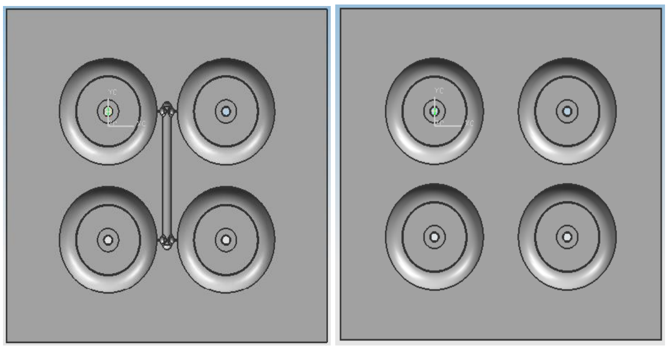


Fig. 4.2(a) Fig. 4.2(b)

Figure 4.2 Old design for wheel tyre (a) Cavity plate (b) Core plate

Same as like inner wheel core runner used in wheel tyre in old injection mould is half runner. Hence, again the modification in new mould is done by changing runner layout and runner type. For new injection mould tool of wheel core the parting runner is used. This doubles the volume of new runner than the old runner. And the runner layout is as shown in fig.5.3.

i) Volume and Weight of the wheel [17]

Volume of wheel tyre (V) = 13.32 cm^3

(From CATIA model)

Density of Polyvinyl Chloride (ρ) = 1.5g/cm^3

Weight of wheel core = V × ρ = 19.98g

ii) Runner Diameter Calculation [17]

$D = (\sqrt{W} \times \sqrt[3]{L}) / 3.5 = (4.47 \times 2.88) / 3.5$

Where, L = Length of Runner = 24mm

W = Weight of wheel = 19.98g

Hence, Diameter of runner = 3.678mm

Assumed Diameter = 3.7mm

Hence, semi circular cross sectional runner is selected.

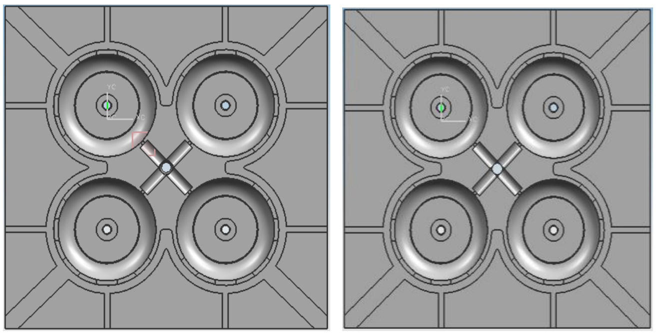


Fig. 4.3(a) Fig. 4.3(b)

Figure 4.3 New design for wheel tyre (a) Cavity plate (b) Core plate

Air vents are design as shown in fig. 4.3. Cooling circuits and other parts used for the wheel tyre injection mould is same as the inner wheel core injection mould.

C. Analysis by Mould Flow

As describe in section 4.4 the need and importance of Mould flow analysis will predict potential quality issues in the part such as flow lines, weld lines, deep under cuts, inadequate draft angles, war page and sink marks. This means that part design changes can be made immediately to address these issues with little time and cost. This affects on the productivity. Hence, the design of new wheel tyre is being analyzed in Mould flow software before actual manufacturing for its validation and approval.

- **Comparison of mould flow result**

- **Case 1 : New design with old runner**

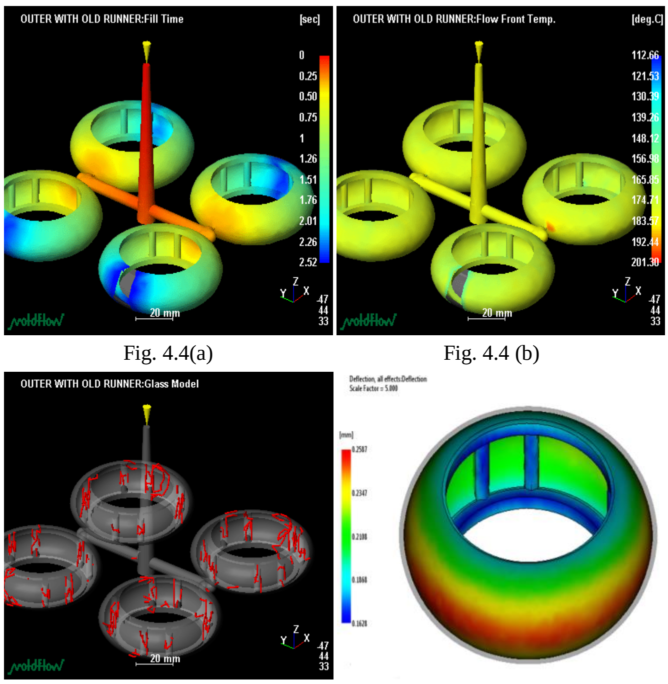


Fig. 4.4(a) Fig. 4.4 (b)

Fig. 4.4 (c) Fig. 4.4 (d)

Figure 4.4 MFA of New design old runner (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis (e) Sink marks analysis

- **Case 2 :** New design with new runner

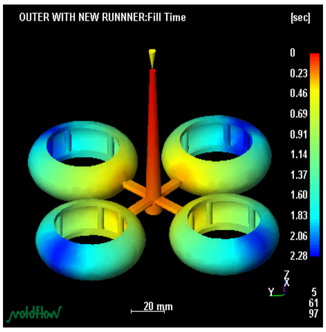


Fig. 4.5(a)

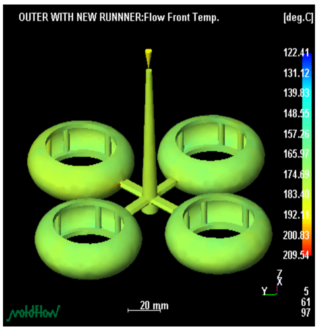


Fig. 4.5(b)

Fig. 4.5(c)

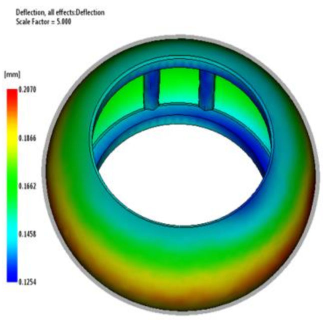


Fig. 4.5(d)

Figure 4.5 MFA of New design new runner (a) Fill time (b) Flow front temperature (c) Weld Lines (d) Warp age Analysis

Table 4.1 Results of mould flow analysis for Wheel Tyre

Parameters	New Design Old Runner	New Design New Runner
Fill Time(s)	2.52	2.28
Shot Volume(cm^3)	56.20	56.30
Flow front temp(°C)	201.30	209.54
Confidence of fill	Low	High
Air traps	Yes	Yes
Warp age in all direction(mm)	0.2587	0.2070
Sin marks	0	0
Weld Lines	Yes	Yes

From the mould flow analysis the new design with new runner showed the best result. Hence, from the Mould flow analysis confirmation the new design with new runner for wheel tyre is selected.

Mass of the old wheel tyre is 0.024 kg and mass of new wheel tyre is 0.02 kg. The difference is of 0.004 kg i.e. 4 g. It means using new wheel design 4g is saved after per wheel tyre.

V. EXPERIMENTAL VALIDATION - MOULD MANUFACTURING AND PRACTICAL ANALYSIS

A. Mould Manufacturing

The 3D drawings were converted to 2D drawings for each part as shown in table 5.1. The fabrication work was done. For manufacturing various machines were used in different steps. Initially rough machining is done by milling machine. Rough machined product is then further given for rotary grinding and surface grinding. Then further operations are done using VMC machines. Further for forming cavity in core and cavity plate EDM process is used in which copper electrode is manufactured having shape like required product. EDM is a simple process in which a shaped electrode, usually made of copper or graphite, is very slowly lowered onto the mould surface, which is immersed in paraffin oil. A voltage applied between tool and mould causes spark erosion of the mould surface in the inverse shape of the electrode. Hence, by spark EDM and by using copper electrode the material is removed from the cavity and core plate. Wire EDM is used for ejector holes. At the end the mould manufacturing is followed by finishing, bench work and assembly.

The dimensions and material of various parts of injection mould tool are shown in table 5.1.

Table 5.1 Part List of Injection mould tool for new design

Sr. No	Component	Size	Material	Quantity
1	Cavity Back Plate	325×325×32	C-45	1
2	Core Back Plate	325×325×28	C-45	1
3	Cavity Housing	325×325×45	C-45	1
4	Core Housing	325×325×74	C-45	1
5	Core Plate	220×210×30	H-14	1
6	Cavity Plate	220×210×30	H-14	1
7	Ejector Plate	325×165×20	C-45	1

8	Ejector Back Plate	325×165×22	C-45	1

Fig. 5.1 shows the assembly of injection mould tool used to manufacture the inner wheel core and the wheel tyre using all the same components except cavity and core plate. Cavity and core are different for inner wheel core and wheel tyre as shown in fig. 3.4 and fig. 4.3.

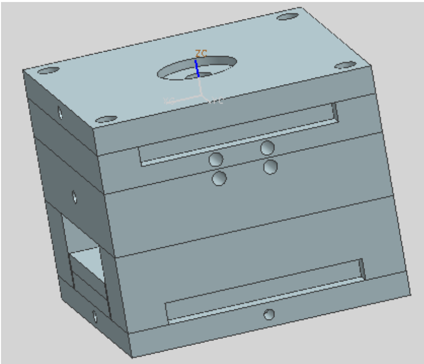


Figure 5.1 3D model of injection mould tool for new design in UG

B. Product Manufacturing

Initially sleeve was kept as an insert in inner core mould. Then the new designed inner wheel core is manufactured. Then by keeping it as an insert in new mould of wheel tyre final new luggage bag wheel is manufactured.

Figure 5.2 New wheel product

C. Practical Analysis

Fig. 5.2 shows the final new luggage bag plastic wheel, from this it comes to know that the problem of deformation of inner core edges is been overcome. To prove the new wheel design is more superior then the old one, the practical validation is done by comparing three models of luggage bag plastic wheel i.e. Old design with good manufacturing, old design with defective manufacturing and new proposed design. Comparison was done by the balancing and compression tests.

VI. RESULTS AND DISCUSSION

- **Cycle Time Comparison**

From the software and experimental analysis, it results that due to change in runner and design of component the required cycle time for product is reduce with the high stability. As the result shows the decrease in injection time for new wheel core and wheel tyre, it decreases the cycle time required to manufacture the new wheel core and wheel tyre. Cycle time required for the old inner wheel core is 70sec and new inner wheel core is 56sec. And cycle time required for the old wheel tyre is 90sec and new wheel tyre is 42sec.

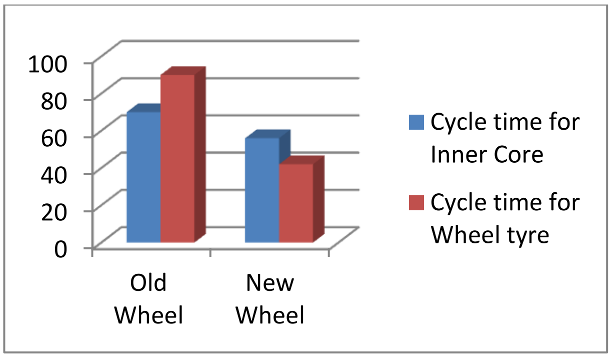


Figure 6.1 Comparison of cycle time

- **Material Cost Reduction**

From above discussion it is seen that the extra material required for new inner wheel core is 2.5g whereas less material is required for the new wheel tyre by 4g.

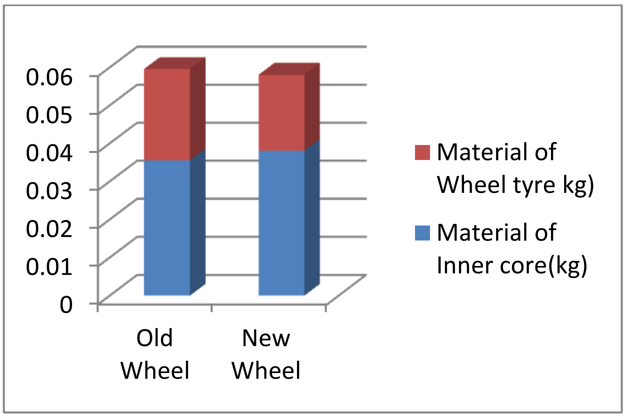


Figure 6.2 Comparison of required material for wheel product

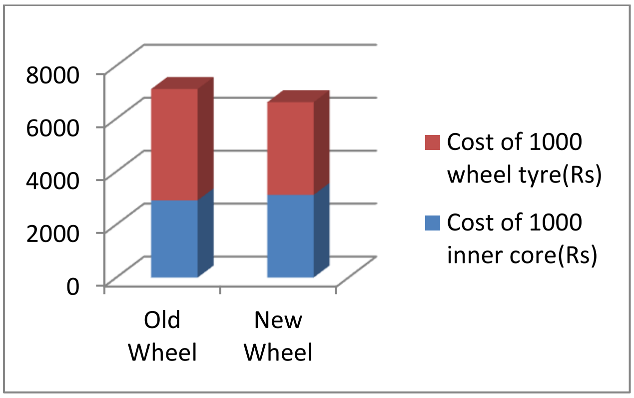


Figure 6.3 Comparison of cost for wheel product

Fig. 6.3 shows that the material and cost required for new wheel product is less compared to old wheel.

- **Process Cost Reduction**

As described in the problem statement, the number of rejection of luggage bag plastic wheel product was more and hence, due to that the initial injection mould tool for plastic was rejected. This leads to waste of mould material, its required cost and time. This all have been saved by the use of mould flow analysis software. Which have reduced the cost required for hit and trial method.

- **Comparison of Old and New Product**

The product analysis is done by comparing the Old and New wheel product by balancing and compression test. It was found that the load bearing capacity of old wheel is 9.10kN and that of new wheel is 10.6kN. Whereas, its balancing results showed that the new wheel is balanced compared to old wheel.

VII. CONCLUSION

- The new design reduces the stresses on inner wall which resist the deformation of walls of inner core. Hence, the edge bending problem is overcome. The rework on the machine is ultimately reduced.
- The cycle time of new inner wheel core is reduced by 26sec whereas for wheel tyre is reduced by 48sec.
- Material cost saved after every 1000 wheel product is Rs. 494.
- The new wheel product is found to be highly balanced and having high load bearing capacity compared to the old wheel product.
- Using Mould flow analysis software to analyze the injection mould reduces the cost required for hit and trail method to manufacture mould and to select process parameters.

VIII. FUTURE SCOPE

1) Study can be done by changing the material of parts.
2) Using different design for inner wheel core the study can be continued.
3) Fatigue analysis can be done to predict the fatigue behaviour and life of the luggage bag plastic wheel.

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