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Re-engineering of Cast Product by Topology Optimization

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ABSTRACT

Topology optimization is useful to carrying out the weight reduction and in process cost reduction can be achieved. This kind of optimization input shape and size modification and optimization give us improved product in reduction of material. For this study, planet pinion carrier is selected for topology optimization. Software gives an innovative real-time picture of company activities and ecosystem and links people, ideas and data in a single collaborative environment. The 3DEXPERIENCE platform as an operating system helps companies to achieve operational excellence. Casting is a process where allowances and other things are provided and if we could able to optimize the material and weight of the casting there is a scope for optimization the material size and shape in casting process. Planet pinion carrier which is a cast product is taken from well-known industry for topology optimization. For optimization that product first 3D model is done and this 3D model is given as an input for topology optimization software. Force analysis is carried out by using ANSYS software and then topology optimization procedure is applied accordingly product is optimized. After topology optimization again force analysis is carried out. It has been found that 20 percent reduction is observed in this study. The part details and load conditions are given by well-known industry for topology optimization. Size, shape and cost is reduced by giving various load conditions in FUSION 360 software. Modeling and remodeling is done using software. Comparative study has been done using AUTOCAST software. Part details are calculated and also casting flow and real time for actual casting is simulated by using software.

Key words: Topology Optimization, Generative Design, Casting.

1. INTRODUCTION

Topology optimization is a mathematical approach that optimizes the spatial distribution of material within a specific area by meeting previously set restrictions and reducing a predefined cost function [1]. The 3DEXPERIENCE gives an innovative real-time picture of company activities and ecosystem and links people, ideas and data in a single collaborative environment. 3D experience software is used for modeling planet pinion carrier and after topology optimization remodeling is also done using this software. 3D experience software has wide range of application and work in collaborative space that create easier way to make 3D model of selected product. Casting is a method of engineering typically utilized for mass manufacture in which materials are poured into a mold in a molten condition where they harden. During this technique, complicated components may be created inexpensively and quickly, which would normally need a long period if generated by other processes, such as shaping or cutting [2]. Topology optimization is carried out on selected product that is planet pinion carrier selected from well-known industry. Selected product is regular product cast in reputed industry and it is used as torque convertor in heavy duty vehicles. Planet pinion carrier is manufactured by using casting process in mass production so if small amount of material were removed by using topology optimization not only weight reduced but also cost for manufacturing this product reduced.

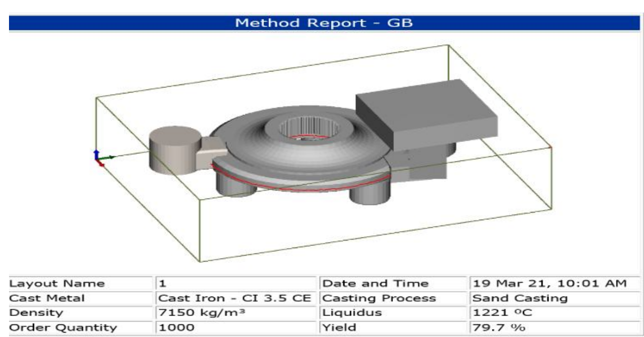


Figure 1: Planet pinion carrier design and dimension details.

Figure 1 shows planet pinion carrier design and dimension details generated in software design includes feeder, runner and riser. This is generated automatically in software by providing part details and finalize by best outcomes generated in software. Table 1 shows dimension details as part surface area, min. Thickness, part weight, maximum Thickness and part volume. Software generates report as per table 1 for planet pinion carrier part mold details and costing details.
Design for metal casting principles in the design of wax patterns for rapid metal casting was proposed by Wanga et al

[3]. Metal casting is helpful when it is either too expensive or time-consuming to manufacture in bulk using other manufacturing techniques. Also they studied various 3d printed parts and done optimization by using simulia module for topology optimization. Provide case study for various parts of investment and metal casting and other work for extrusion commercial topology optimization.

Table 1: Planet Pinion Carrier Part and Mold Details.

Part details			
Parameter	**Details**	**Parameter**	**Details**
Dimensions	134*256.64*256.27 mm	Part Surface Area	1813.64 cm²
Min. Thickness	2.57 mm	Max. Thickness	51.64 mm
Part Weight	16.19 kg	Part Volume	2166.1 cm³
Mold details			
Mold Material	Green Sand	Density	1550 kg/m³
Dimensions	185.33*307.97*307.59 mm	Parting Orientation	Horizontal
Number of Cavities	x	Draw Distance	N/A
Min. Cavity-Wall Gap	25.66 mm	Metal / Sand (weight)	67.87 %
Min. Cavity Gap	N/A	Metal / Sand (Volume)	14.07 %
Total Material Cost	638 Rs	Total Cost	986 Rs

The Innovation management includes all responsibilities of planning, decision-making, organization and control in the creation and implementation of innovative ideas in marketable services. A similar study is reviewed from the paper presented by Niewohner et al. [4]. They established concept of digitalization in the area of design as an incentive for creativity, ideas and invention. Under those topics they subdivided three subtopic processes as organization, culture and strategy.

Walton and Moztarzadeh [5] demonstrated topology optimization of pair of rear uprights which are main structural member of suspension assembly made from Ti-6Al-4V alloy with an objective of weight minimization. In the simulation process the design was constrained to a maximum mass of 0.6 kg and a maximum stress of 450MPa. Topology interpretation was completed by tracing the optimized mesh in Solid Works 2014 which allowed modifications in geometry as rounding of edges and tooling access for support removal. The topology interpretation stage was completed in approximately 20 hours.

Srivastava et al. [6] developed a model of Korean passenger vehicle bogie frame for fatigue constraint weight optimization. Finite Element (FE) methods were used to evaluate fatigue strength of bogie frame. Further 4.7%weight of bogie frame was reduced through Genetic Algorithms (G.A.). Shukla et al. [7] developed a Multi body dynamics model of CASNUB freight bogie to improve riding of the vehicle performing parametric study of suspension elements. Kim et al. [8] performed experimental structural analysis of Korean tilting train bogie bolster by means of two ways i.e. static and fatigue loading test. The safety against fatigue was checked using Goodman diagram of the material used.

In this section introduction about the casting process, topology optimization and product which is selected for carried out the work is maintained. The related literature is reported. The rest of the paper is organized in following sections. The methodology of the topology optimization and the casting process is explained in Section 2. The modeling part and meshing of the planet pinion carrier related things are maintained in section 3. Section 4 deals with the topology optimization of the product under consideration. Results are discussed in section 5 and finally the conclusion is mentioned in section 6.

2. TOPOLOGY OPTIMIZATION METHOD AND CASTING PROCESS

Name of the selected product is planet pinion carrier, R182471 is the product number. Version of planet pinion carrier is JD90. Material for the product is not painted cast iron. Material properties are as per RES10404. Casting soundness for the product is JDT17015. Planet pinion carrier made from R332414 which height is 137mm and diameter is 257mm, volume of this product is 2382116.3mm3. Planet pinion carrier used as torque converter in tractor and JCB etc. Grey cast iron used for making planet pinion carrier part in mass production. In reputed industry planet pinion carrier R182471 made by casting process and after casting machining is also carried out.

Figure 2 shows casting process of planet pinion carrier in which Feeder, runner and riser are provided automatically in software by providing part details. Figure 2 indicates intermediate casting process where molten metal pouring in mold cavity. Solidification process after molten metal totally poured into mold cavity. Temperature during solidification was shown by various colors. Every color indicates different temperature as in figure and chats for temperature measurement are provided in left corner.

Load conditions of planet pinion carrier are explained below. 150 N bearing load applied to the base cylindrical shape rod and 350 N load applied to the center bearing teeth. Arrow shows direction of load and red color indicates load area.

Load conditions provided by reputed industry. Figure 4 shows area where load applied. Bearing load is applied on that area blue color area shows central teeth area (CTA). Cylindrical support on which pinion gear is mount and bearing load is applied on that area. Red color area indicates 3 cylindrical support pinion gear carrier (SSPGC).

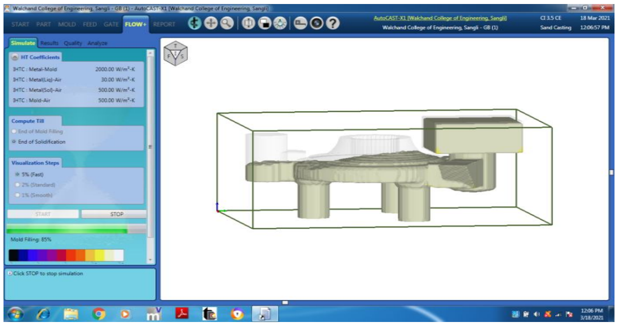


Figure 2: casting process of plant pinion carrier.

Table 2 shows load conditions for case 1 that is 100N bearing load applied on 3 cylindrical support pinion gear carrier and 250N bearing load applied on central teeth area. Range for load condition for 3 cylindrical support pinion gear carrier is 100 to 200N and for central teeth area is 250 to 350N. so it categories into 3 load condition case where in case 1 minimum load applied on planet pinion carrier that is 100N for 3 cylindrical support pinion gear carrier and 250 N for central teeth area.

Table 2: Load Conditions for Planet Pinion Carrier.

Sr. No.	Condition	Load
1	Load condition 1, 2 and 3. (SSPGC-1)	100, 150 and 200 N
2	Load condition 1, 2 and 3. (SSPGC-2)	100, 150 and 200 N
3	Load condition 1, 2 and 3. (SSPGC-3)	100, 150 and 200 N
4	Load condition 1, 2 and 3. (CTA)	250, 300 and 350N

Topology optimization carried out in fusion 360 software on planet pinion carrier. For load condition 1 that is explained earlier. Cylindrical support and fixed constrains are provide for better results. Material was removed from non-preserved area. For minimum load condition maximum material were removed by topology optimization. Software provide various models where red area shows stresses on that area for load condition 1. Finalize model by choosing suitable design for minimum deformation for load condition 1.

3. 3D MODELING AND MESHING OF PLANET PINION CARRIER.

For selecting casting product, three casting reputed industries have been visited. They provided various casting component and details. By analyzing this component planet pinion carrier R182471 component has been selected, on which topology optimization can be done. 2D drawing was provided by industry. By using 3D experience software model was created as shown in figure 3 for creating model of cast product (planet pinion carrier) various models are used in 3D experience software.

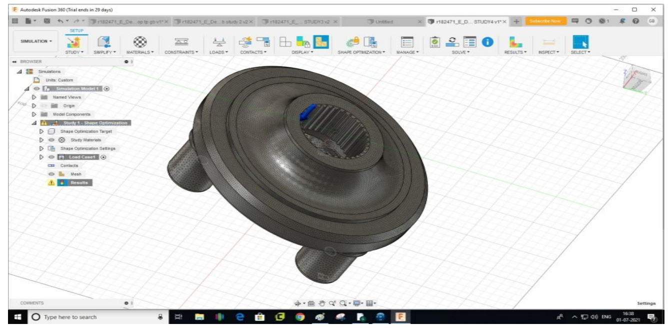


Figure 3: Planet Pinion Carrier Meshing

In FUSION 360 software, the mesh generation tool is utilized for meshing. Mesh with lowest nodes of 2mm and maximum nodes of 5mm was created using the hex-dominant auto mesh method [9]. Following are the meshing of the product show in figure 3.

4. TOPOLOGY OPTIMIZATION OF PLANET PINION CARRIER

Topology optimization carried out in fusion 360 software on planet pinion carrier for load condition 1, 2 and 3. Cylindrical support and fixed constrains are provide for better results. Figure 4 shows optimized planet pinion carrier for load condition 1. Figure 5 shows optimized planet pinion carrier for load condition 2 and figure 6 for load condition 3. Material was removed from non-preserved area. For minimum load condition maximum material were removed by topology optimization. Software provides various models as shown in figure 4, 5 and 6. Where red area shows stresses on that area for various load conditions. Finalize model by choosing suitable design for minimum deformation [10].

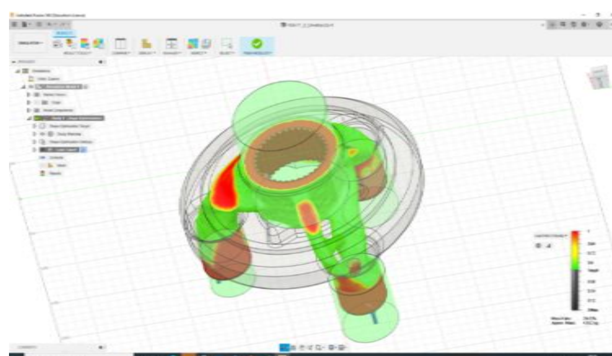


Figure 4: Topology Optimization of Planet Pinion Carrier for Load Condition 1.

Remodeling carried out in 3D EXPIRIENCE software on planet pinion carrier for load condition 2 that is average load condition. By comparing FUSION 360 software results for load conditions, it shows that for average load condition optimized results are better from deformation, stress and strain study [11]. Factorial design based optimization is carried out by Surapong et al. [12].

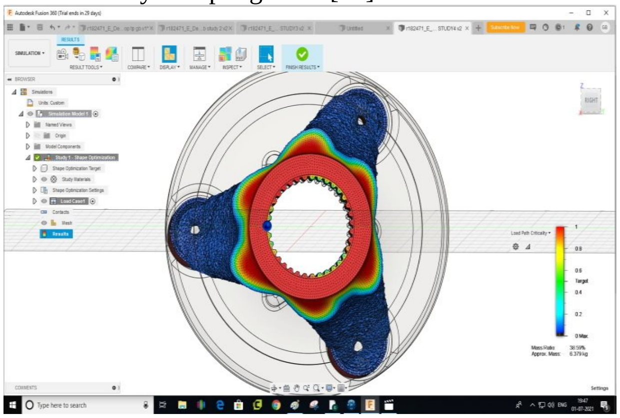


Figure 5: Topology Optimization of Planet Pinion Carrier for Load Condition 2.

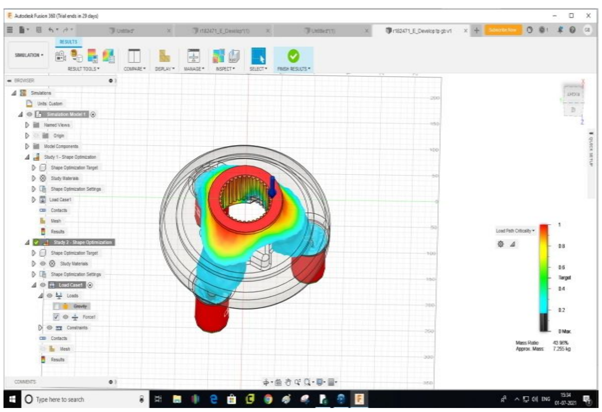


Figure 6: Topology Optimization of Planet Pinion Carrier

Figure 7 shows optimized planet pinion carrier after remodeling in 3D EXPIRIENCE software.

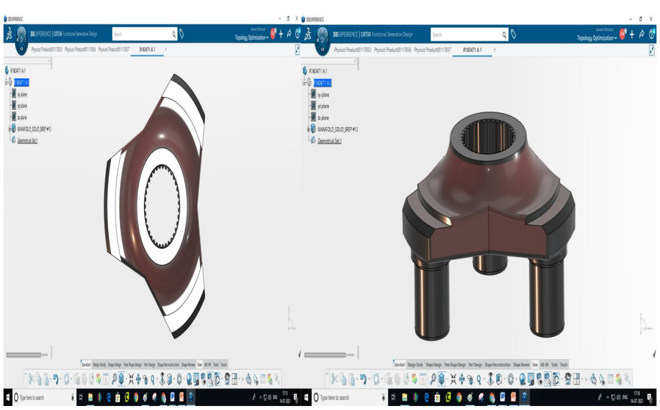


Figure 7: Topology Optimization of Planet Pinion Carrier (Remodeling)

5. RESULTS AND DISCUSSION

Figure 8 shows deformation of planet pinion carrier. Directional deformation shows figure 9 in which red colour indicates load area. Figure 10 shows equivalent elastic strain of planet pinion carrier where maximum value is 5.7223e-6 and minimum value is 1.8727e-9. Figure 11 shows stress for planet pinion carrier.

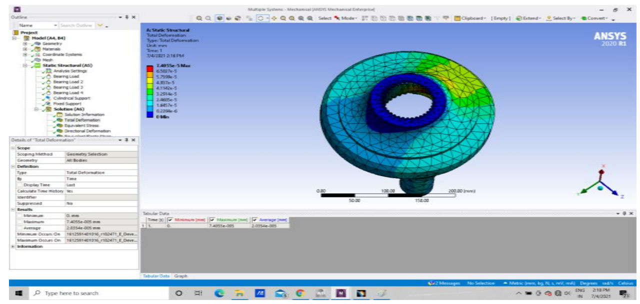


Figure 8: Deformation of Planet Pinion Carrier.

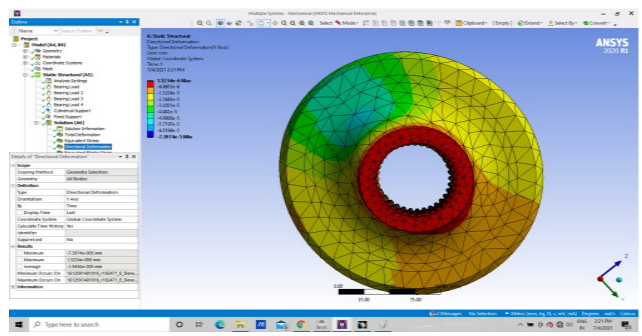


Figure 9: Directional Deformation of Planet Pinion Carrier.

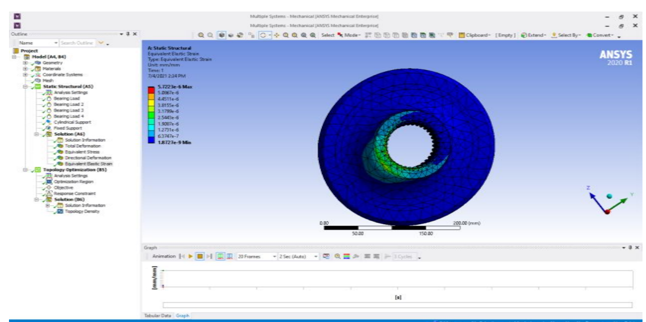


Figure 10: Equivalent Elastic Strains of Planet Pinion Carrier.

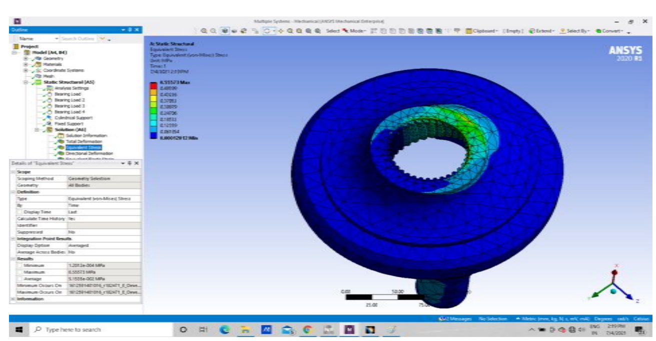


Figure 11: stress for Planet Pinion Carrier.

For comparative study again Deflection deformation, Equivalent Elastic Strain, Equivalent Stress and Total deformation results are taken by simulation. Figure 12 shows Directional Deformation for Planet Pinion Carrier, where maximum value is 1.967e-5 and minimum value is -2.0269e-5.

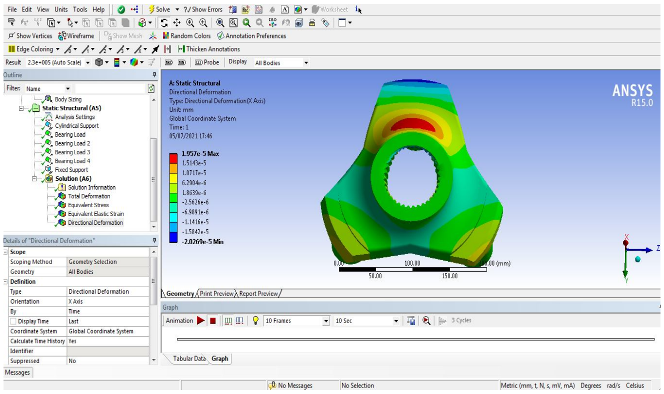


Figure 12: Planet Pinion Carrier Directional Deformations after Topology Optimization.

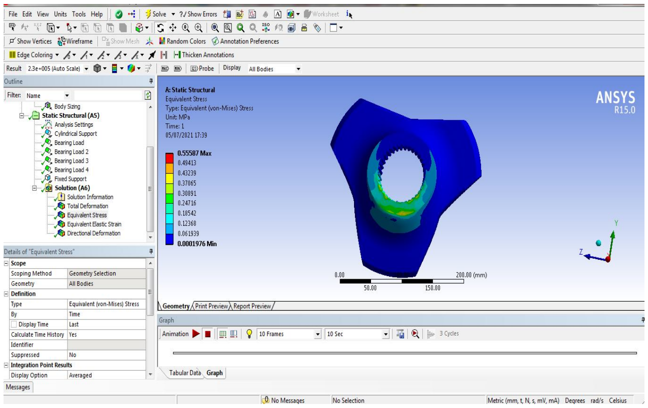


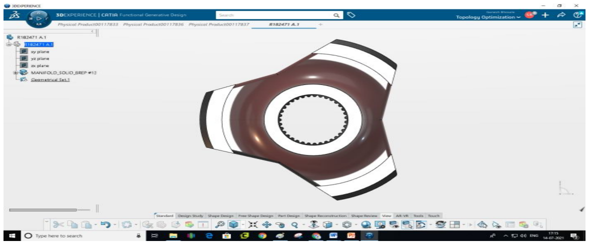
Figure 13: Equivalent Stress of Planet Pinion Carrier after Topology Optimization.

Figure 13 shows Equivalent stress for planet pinion carrier after topology optimization carried out under 100KN to 350KN load condition. Where minimum equivalent stress is 0.0001976 MPa and maximum equivalent stress is 0.55553 MPa.

6. COMPARATIVE EVALUATION

Figure 14 (a) shows planet pinion carrier before and (b) after topology optimization.

(a)



(b)

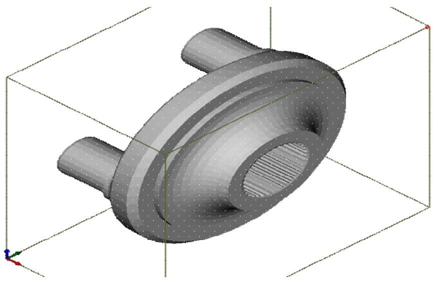
Figure 14: before and after Topology Optimization of Planet Pinion Carrier

Dimension of planet pinion carrier before optimization was 134* 256.64*256.27 mm and after optimization it was 134 * 223.18 *250.93 mm. volume also changed from 2166.1 cm^3 to 1760.18 cm^3. Because of material removed, total cost also reduced from 986 Rs to 852 Rs. Surface area changed from 1813.64 cm^{23} to 1520.01 cm^2.

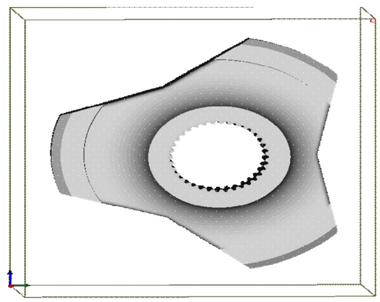
Table 3: Before and After Topology Optimization of Planet Pinion Carrier Comparison

Sr. No.	Parameters	Before Optimization	After Optimization
1	Dimension	134* 256.64*256.27 mm	134 * 223.18 *250.93 mm
2	Volume	2166.1 cm^3	1760.18 cm^3
3	weight	16.19 kg	13.16 kg
4	Max. Thickness	51.64 mm	49.75 mm
5	Total Material Cost	638 Rs	638 Rs
6	Total Cost	986 Rs	852 Rs
7	Density	7200 kg/m^3	7200 kg/m^3
8	Casting temperature	1176 ºC	1176 ºC
	Surface Area	1813.64 cm^2	1520.01 cm^2
9	Mold dimension	185.33 mm X 307.97 mm X 307.59 mm	184.19 mm X 273.37 mm X 302.37 mm
10	Mold Density	1550 kg/m^3	1550 kg/m^3

Figure 15 shows result in AUTOCAST software for planet pinion carrier in which (a) shows before optimization and (b) shows after optimization planet pinion carrier details are conducted through AUTOCAST software.



(a)



(b)

Figure 15: before and after Topology Optimization of Planet Pinion Carrier in AUTOCAST Software.

7. CONCLUSION

Topology optimization has been done on planet pinion carrier. The planet pinion carrier was optimized with the help of software. Weight and size of planet pinion carrier were reduced so that cost of that part also reduced. It has been shown that, approximately 15 to 35 percent weight was reduced by topology optimization for various case studies. Comparative study has been done on software. Design of mold, feeder, runner and riser has been changed because of topology optimization.

Optimized Physical product (planet pinion carrier) can be cast and it can be compared actually with previous product. There is also scope for changing material properties of planet pinion carrier.

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