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Cost benefit analysis of Rapid Manufacturing in Automotive Industries

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Abstract: - This paper deals with the application of rapid manufacturing techniques to save the time as well as cost of manufacturing of few critical components of automobiles. A case study of Inlet manifold of engine and Rotor of disk break is taken here to demonstrate the method. While working on this objective the aim will be to reduce the lead time required for tooling required for the conventional block-type investment casting process. There are strong incentives to reduce costs while increasing speed and accuracy in the current market. RP is an ideal method when the components are complex in shape because it substantially compresses the time for developing prototypes, patterns and tooling. This method is even more promising on cost and time front. The capabilities to fabricate freeform surfaces, inbuilt cores, projections and supports are the unbeatable strengths of RP processes. The use of benefits in terms costs have proved that the adoption of RP technology is techno-economically justifiable for the Indian manufacturing industries. Rapid Prototyping have proved to be a cost-effective and time efficient approach for development of pattern making, thereby ensuring possibility for technology transfer in Indian manufacturing industries.

Keywords: - Rapid Prototyping, Cost benefit analysis, Casting Cost estimation

1. Introduction

With the rapid development of the automobile industry the manufacturing of the pattern for the inlet manifolds and rotor at low cost, with a short manufacturing cycle, is the key factor for the competitive automobile industry. The short- comings of the traditional investment casting are: a complex process; a long manufacturing time; high cost; pose the bottleneck of pattern making [10]. In today's competitive environment, the manufacturing industries are striving for development of next generation products due to increasing competition among the products and continuously changing customer needs. Among the challenging tasks the manufacturers are facing include, increasing product complexity. This has emerged the concept of rapid physical realization of products well before its manufacturing [1].

A dominant technology for producing physical models for testing and evaluation purposes has been Rapid Prototyping (Horvath and Yang, 2002). Rapid Prototyping (RP) techniques are fast becoming standard tools in the product design and manufacturing industry. The zero tool costs reduced lead times and considerable gains in terms of freedom in product design and production schedules are the appreciable facts regarding RP (Hopkinson and Dickens, 2001). The parts those were previously impossible or extremely costly and time consuming to fabricate can be built with ease with RP. The RP techniques are limited neither by geometry nor by the complexity of parts to be fabricated [9].

In metal casting processes, conventionally the development of patterns greatly influence cost and dimensional quality of the product. Comparing the lead-times required for fabrication of sacrificial pattern and patterns produced with RP, allows significant amount (89%) of time-saving (Lee, et al., 2004). It has been claimed that RP can cut new product costs by up to 70% and the time to market by 90% (Pham and Gault, 1998). To stay a head in competition, the updated technology demands development of fast and accurate products of high standards [2].Therefore, the time and cost effective advantage of Rapid Prototyping philosophy can be utilized for development of rapid tooling by transferring the technology in investment casting industries. Following are the significant reasons that create a need for technology transfer in the conventional industries [1]:

1. Rapid Prototyping is an automated fabrication process. Hence, it requires minimal human intervention.
2. It can build arbitrarily complex 3D geometries directly from CAD data.
3. It drastically reduces product development cycle time, because the product is directly fabricated

from CAD data and process planning is almost eliminated.

4. It uses a generic fabrication machine, i.e., it does not require part-specific fixture or tooling.
5. The process planning is automatic, based on the CAD model.
6. It is most suitable for production of customized or single product.
7. There is no need of assemblage of the components. All the components in assembly are fabricated simultaneously, a layer-by-layer. A support material is used to fill-up the cavities.

2. Need and scope for effect of Rapid prototyping in manufacturing industries

The idea of using RP machines for the manufacture of products in high or medium volumes seems unrealistic as the cycle times, material costs and capital equipment for processes such as injection moulding are far lower that RP. However, many researchers appreciated the zero tool costs, reduced lead times and considerable gains in terms of freedom in product design and production schedules using RP. (Chiang, et al., 2005; Folkestad and Johnson, 2002; Hopkinson and Dickens, 2001; Karapatis, et al., 1989; Mueller, 2005; Rooks, 2002; Wang, et al., (1999)[1]. The layered manufacturing techniques are economically comparable with conventional castings processes for the manufacturing of the patterns. These facts highlight the need for technology transfer by developing a method for the rapid manufacturing of patterns.

Rapid Prototyping techniques involve no tooling or fixtures, resulting in simpler set-up, lower overhead cost and shorter production lead times. The parts that were previously impossible, extremely costly and time consuming can be built with an ease with RP. The mass production tools such as molds and dies can be made ready with an ease and short time with RP. The need for use of RP in pattern making is due to following reasons [1]:

1. RP fabrication process is automated
2. Fabricates intricate and small parts
3. Substantial reduction in lead time
4. Eliminates tooling
5. Eliminates process planning
6. Customized product
7. Produces no scrap
8. No assemblage of parts

The scope of research in few areas appeared to be:

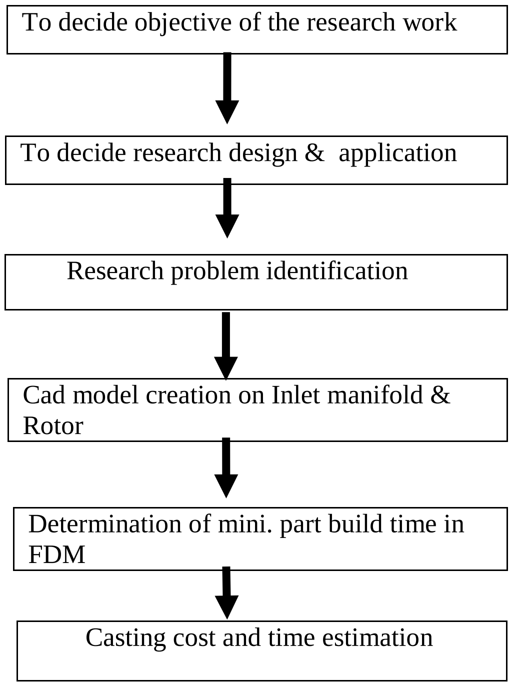
- Scope for technology transfer in foundry industry.
- Determination of minimum part builds cost in FDM.
- Cost/benefit analysis for rapid prototyping industry.
- Casting cost estimation for investment casting.

3. Objective and Methodology

The objectives of study are:

1. Study of RP in context to an automotive industry
2. Study of RP as a technology transfer for automotive industry.
3. Study of effect of RP techniques especially on manufacturing modules in automotive industries considering cost and time aspect.
4. To conduct a techno economical Study of effect of RP techniques especially on manufacturing.
5. To check the feasibility with the help of a case study from automotive industry with the help of inlet manifolds and rotor.

The methodology for this we have used as follows:



3.1 Research Problems

Problems identified by performing a market survey in various automobile workshops in Nagpur. Most of the people in the repairing shop are facing problems regarding inlet manifold and rotor. When this inlet manifold and rotor part break-down, then workshop person require some special order for casting of that product. The following problems facing by the workshop persons are,

1. Cost of pattern making is too costly.
2. Time requires for pattern making of inlet manifold and rotor is more.
3. Complex size shapes are difficult to prepare.
4. Especially order require for these products.
5. Less availability of part in market.

3.2 Cad Model Creation of Inlet Manifold and Rotor

Designing of 3-D CAD model of part using CAD software PRO-E, This work is primary function of the research work. This is creation the CAD model for further process.

3.2.1 Cad Model of Inlet Manifold and Rotor

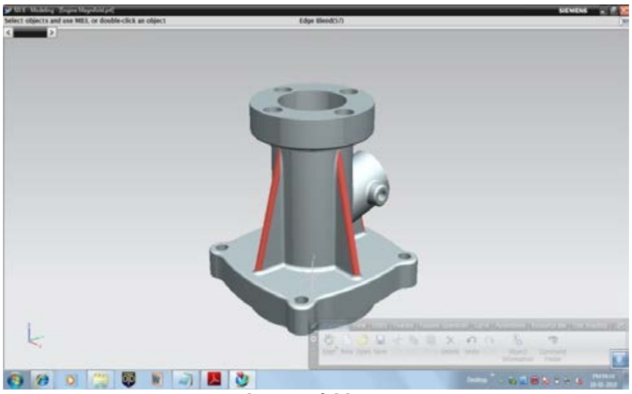


Figure 1 Isometric view inlet manifold

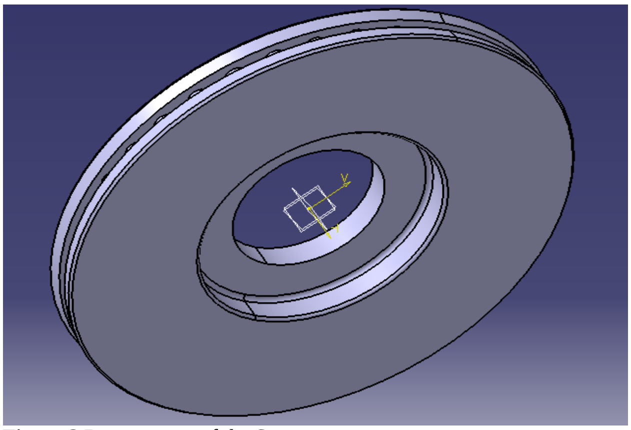


Figure 2 Bottom view of the Scorpio rotor

3.3 Determination of Part Build Cost in FDM

In order to determine the total cost of part preparation in FDM rapid prototyping process, the influencing parameters are considered. The material cost is computed on the basis of volume of model and support material required to build the part and unit price of material. The FDM process employs external support structure to the part being built. The total build material consists of model a material and the support material. The costs associated with other dominant parameters include, base plate cost (C_{pa}), electricity cost (C_{el}), battery depreciation cost (C_{bd}), machine depreciation cost (C_{md}), and the annual maintenance cost (C_{md}) and the annual maintenance cost (C_{am}). The pre or post processing in RP does not differ considerably for different types of parts. [1]

To carry out the cost analysis, following costs elements are considered:

1. Direct materials
2. Direct labor
3. Direct expenses
4. Overhead.

The values of various cost components are summarized as follows which is taken from literature review: [1]

1. Model material cost (c_{mm}) : Rs.13.95/cm^3
2. Support material cost(c_{sm}): Rs.13.95/cm^3
3. Base plate cost(c_{pa}): Rs.267.5 per plate
4. Annual maintenance cost (c_{am}) : Rs.0.913/min
5. Electricity cost (c_{el}) : Rs.0.012/min
6. Battery depreciation (c_{bd}): Rs.0.01826/min
7. Machine depreciation (c_{md}): Rs.0.068/min

After summing up these costs of components, Equation 1 can be formulated to compute the total cost:

$$c_t = c_{mm} + c_{sm} + c_{pa} + (c_{el} + c_{bd} + c_{md} + c_{am}) \ldots\ldots 1$$

Substituting the numerical values of various cost components in equation 1 the equation 2 is formulated:

$$c_t = (13.95 * m_m) + (13.95 * s_m) + (16.72 * C_{pa}) + [(0.913 + 0.12 + 0.1826 + 0.0684) * t_b \ldots\ldots 2$$

Where, m_m *- model material* (cm^3)

s_m - *Support material* (cm^3)

c_{pa} - *Cost of base plate (Rs)*

t_b - *Build time (min)*

The equation 3 gives the relation that can be used to determine the total part build costs in FDM.

$$c_t = (13.95 * m_m) + (13.95 * s_m) + (16.72 * C_{pa}) + (1.11966 * t_b) \ldots\ldots 3$$

3.4 Calculation of Part Build Costs in FDM

With using catalyst software for getting the model material (cm^3) m_m, support material (cm^3)s_m, cost of base plate (Rs) c_{pa}, build time (min) t_b. Of the inlet manifold and rotor in PRO E made cad model.

[1] The Values Are

FOR INLET MANIFOLD

Model material (cm^3) m_m =68.78

Support material (cm^3) s_m = 18.88

Cost of base plate (Rs) c_{pa} = Rs.267.5 per plate, one base plate is require for it

Build time (min) t_b =7.41 hours

Substituting the values in equations 3, the total costs are

Total part cost (Ct) =5703 Rs

FOR ROTOR

Model material (cm^3) m_m =178.16

Support material (cm^3) = 45.40

Cost of base plate (Rs) c_{pa} = Rs.267.5 per plate, one base plate is require for it

Build time (min) t_b =9.45 hours

Substituting the values in equations 3, the total costs are
Total part cost (Ct) =7601.84 Rs

The Part build cost in FDM is representation in following graph

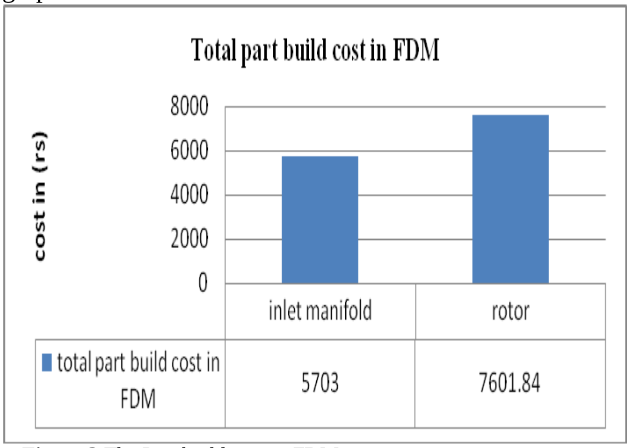


Figure 3 The Part build cost in FDM

3.5 Cost/Benefit Model

The cost incurred and costs saved in the manufacturing processes can be easily quantified. The quantified costs help a lot in making crucial financial decisions. But, it is very difficult to quantify the benefits like: time, functionally, quality, satisfaction, manufacturability, and customization etc. in terms the cost. Rapid prototyping yields above significant benefits over established conventional practices. The quantification of benefits in terms costs are always desirable to evaluate the systems performance. The cost/benefit models are justify implementation of rapid prototyping as a technology transfer and can be used with confidence for predicting the values of significant costs while dealing with FDM [1].

RP technology derives radical change by eliminating the costs in tooling, jigs and fixtures. It dramatically reduces the cost of process planning. As a major change, the human cost is substantially reduced, since RP requires minimum human skill and attention. Finally, the significant change occurs by materially reducing the cost of scrap, rework and assembly [1].

The total cost (C_t): After summing up the machine operating cost (c_0), material cost (c_m), operator cost (c_L) and pre-processing cost (c_p) cost components, equation 4 determines the total cost (C) considering the benefit of RP technology.

$$C = c_0 + c_m + c_L + c_p \quad \ldots\ldots\ldots\ldots\ldots\ldots 4$$

The cost/benefits models are summarized below taking from literature review [1]:

$$C_o = 0.0047 * t_b^{0.99} * \Psi_o^{33.67} * h_f^{4.1}$$
$$C_m = 0.0016 * m_t^{0.87} * \Psi_L^{-39.39} * m_{tu}^{0.219}$$
$$C_L = 0.539 * t_b^{0.998} * \Psi_L^{-24.61} * L_r^{-0.498}$$
$$C_p = 33.82 * t_p^{0.502} * \Psi_p^{-4.76} * L_r^{-0.164}$$

3.5.1 The total cost of inlet manifold and rotor after using mathematical model of cost benefit analysis for determination of minimum build cost & optimal build orientation.

In any RP process, deciding the orientation of part before its actual fabrication is very important. RP parts can be built with infinite number of orientations. The build orientations directly affect build time, volume of material required and surface quality. The optimal part build orientation utilizes the optimum resources. In order to determine the optimum part build orientation, it is necessary to identify such orientation that incurs the minimum build cost [1].

So with the help of cost benefit model we are trying to get minimum build cost and optimum build orientations. This is taking from the literature review. After summing up the machine operating cost (c_0), material cost (c_m), operator cost (c_L) and pre-processing cost (c_p) cost components, equation 4 determines the total cost considering the benefit of RP technology. [1]So total Computed cost with the help of cost benefit model

$$c = c_0 + c_m + c_L + c_p$$

1. The minimum total cost of Inlet Manifold (Ct) =3095 Rs
2. The minimum total cost of Rotor (Ct) =4151 Rs

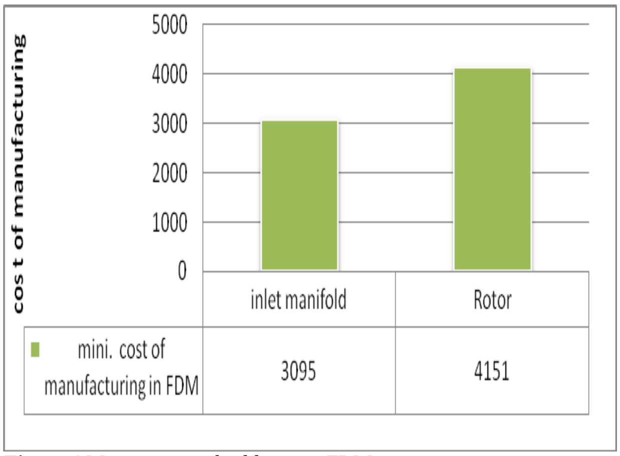


Figure 4 Minimum part build cost in FDM

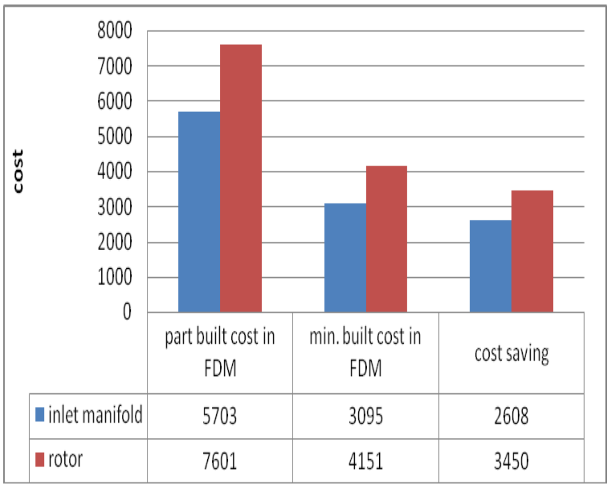


Figure 5 Cost saving with minimum Parts build cost in FDM

The total cost of inlet manifold and rotor after using cost benefit model for determination of minimum build cost from literature review we can save the 2608 Rs of inlet manifold and 3450Rs of rotor part build cost.

4. Casting Cost Estimation

Indian casting industry is booming at a rapid pace and looking at the present scenario one concept that has gained its popularity in past couple of years is "Casting Cost Estimation". These days the competition has grown at the phenomenon rate and in order to survive and compete at a global platform, metal casting industry has to meet ever increasing customers' expectations in terms of quality standards and lower pricing [4].

Casting process planning generally consists of proper choice of suitable casting process and various materials. Now in order to have continuous cost reduction in casting process, it is essential to build up an easy-to-use casting cost estimation methodology. It is also important to note that any comprehensive casting cost estimation methodology must have ability to identify the most important parameters in casting cost. The most important attributes of casting are cost estimation of material and tooling process [3]. The casting cost estimation is carried out for getting benefit of RP in casting industries. The total casting cost is given as the sum of costs corresponding to material, labour, energy, tooling and overheads costs.

$$C_{\text{total casting cost}} = C_{\text{material}} + C_{\text{melting}} + C_{\text{molding}} + C_{\text{core making}} + C_{\text{finishing}} \quad \ldots\ldots 5$$

Other costs related to interest rate, fixed cost, delivery, taxes, duties and premium can be added and calculate for casting cost estimation[3].

4.1 Investment Casting Pattern Cost Estimation

Here we are going to cost estimating of conventional investment casting pattern and total product development cost in casting.

4.1.1 Costing Of Wax Pattern

4.1.1.1 Part: Inlet Manifold

To carry out cost analysis following cost element are considered:

1. Direct materials
2. Direct labor
3. Direct expenses

After calculation following values for wax pattern
Total cost required for inlet manifold Wax pattern

1. Raw material cost =33.76Rs
2. Freight charges =2.5Rs
3. Design cost = 2000/Rs
4. Machining cost =3500/Rs
5. Labor cost =560/Rs

Total cost = 6096Rs

4.1.1.2 Part: Rotor

To carry out cost analysis following cost element are considered:

1. Direct materials
2. Direct labor
3. Direct expenses

After calculation following values for wax pattern
Total cost required for rotor pattern

1. Raw material cost =101.17
2. Freight charges =8.62
3. Design cost = 3500/Rs
4. Machining cost=5000/Rs
5. Labor cost =800/Rs

Total cost = 9410 Rs

4.2 Investment Casting Total Cost Estimation

4.2.1 Part: Inlet Manifold

With using Material: mild steel, Density of MS =7.85 gm/cm3, Mass of the material required = 1.670 kg, Cost of the raw material per unit = 75 Rs/kg, the following value for the inlet manifold
Total cost for casting excluding pattern cost
Total cost of material = 125 Rs
Freight charges = 0.02*125=2.5Rs
Total labor cost =380 Rs
Core box design cost = 1000 Rs
Cost of melting = 695 Rs
Total machining cost = 200Rs
Total cost = 2402 Rs
With Including Pattern Cost =6096+2402, Total cost = 8498 Rs

4.2.2. Part: Rotor

With using**,** Material: mild steel**,** Density of MS =7.85 gm/cm3**, Mass** of the material required = 5.75 kg**,** Cost of the raw material per unit = 75 Rs/kg
Total cost for casting excluding pattern cost
Total cost of material = 431 Rs
Freight charge =0.02*431.25=8.82Rs
Total labor cost =420 Rs
Core box design cost = 1500 Rs
Cost of melting =2393 Rs
Total machining cost = 350Rs
Total cost = 5103 Rs
With including pattern cost =9410+5103, Total cost =14,512 Rs

4.3 Cost Comparison of ABS and Wax Pattern

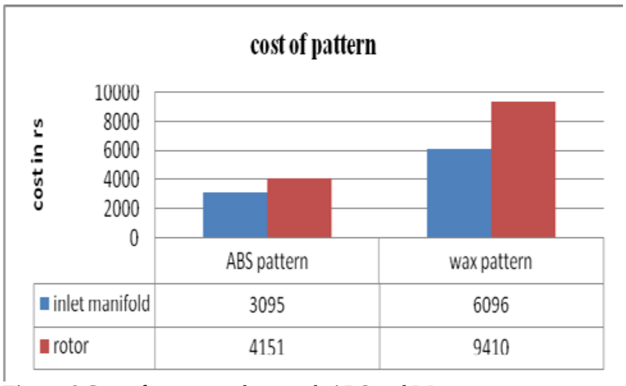


Figure 6 Cost of pattern making with ABS and Wax pattern

With the help of the FDM for pattern making we have save the 3001 Rs for inlet manifold ABS pattern and 5259 Rs for rotor ABS pattern. The cost of WAX pattern making with the use of conventional investment casting method is costlier than the ABS pattern making in FDM.

4.4 COSTING OF INLET MANIFOLD IN INVESTMENT CASTING

Table 1. Costing of Inlet Manifold in investment casting (Rs)

Casting Cost	ABS Pattern	Wax Pattern	Total Cost Saving
Pattern Making	3095	6096	3001
Cost Of Material	125	125	0
Freight Charges	2.5	2.5	0
Labour Charges	380	380	0
Core Box Design Cost	1000	1000	0
Cost Of Melting	695	695	0
Machining Cost	200	200	0
Total Cost	5497	8498	3001

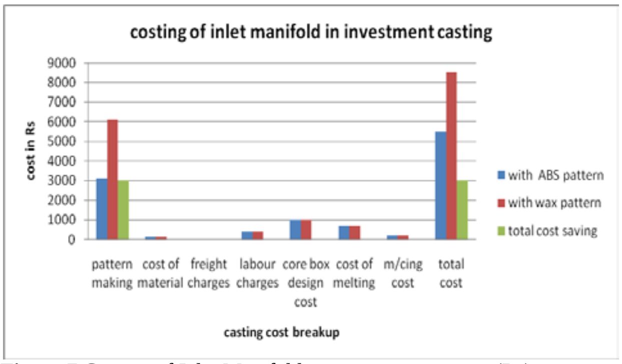


Figure 7 Costing of Inlet Manifold in investment casting (Rs)

So the cost estimation is given the result is with the help of rapid prototyping we can save the cost of inlet manifold is 3001 Rs for single part manufacturing with using RP in investment casting for pattern making.

4.5 COSTING OF ROTOR IN INVESTMENT CASTING

Table 2. Costing of ROTOR in investment casting (Rs)

Cost	ABS Pattern	Wax Pattern	Total Cost Saving
Pattern Making	4151	9410	5259
Cost Of Material	431	431	0
Freight Charges	9	9	0
Labour Charges	420	420	0
Core box Design Cost	1500	1500	0
Cost Of Melting	2393	2393	0
Machining Cost	350	350	0
Total Cost	9254	14513	5259

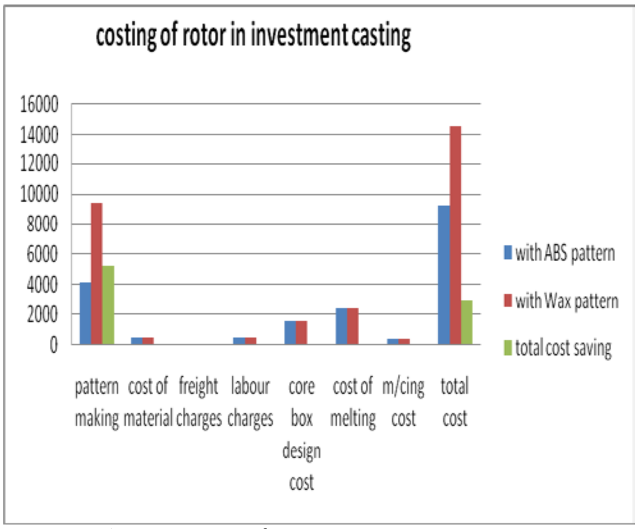


Figure 8 Costing of ROTOR in investment casting

So the cost estimation is given the result is with the help of rapid prototyping we can save the cost of rotor is 5259 Rs for single part manufacturing with using RP in investment casting for pattern making.

5. Lead Time Calculation for Patterns

RP Pattern

Total lead time for RP made pattern=9.41 hours
Total lead time for RP made pattern=12.45 hours

Wax Pattern

Consultation with the experts in the foundry shop, the lead time for inlet manifold and rotor are
Total lead time for investment casting made pattern=16 hours
Total lead time for investment casting made pattern=23 hours

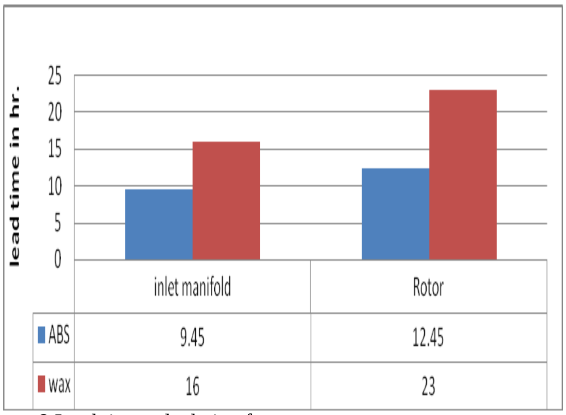


Figure 9 Lead time calculation for patterns

So the lead time for ABS is lesser than the wax pattern, here percentage reduction in lead time as compare with ABS pattern is 59.06 % for inlet manifold and 54.13% for rotor.

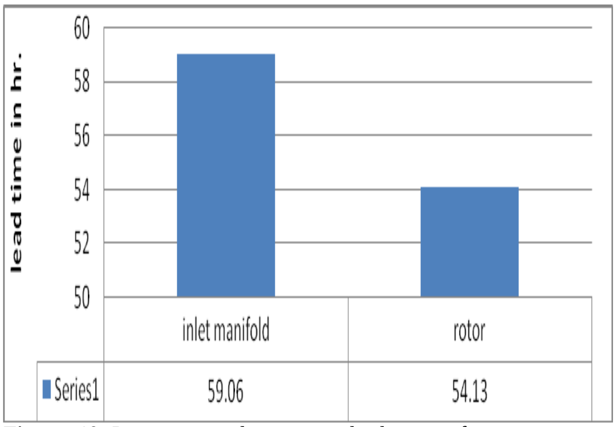


Figure 10 Percentage reductions in lead time of wax pattern as compare with ABS pattern

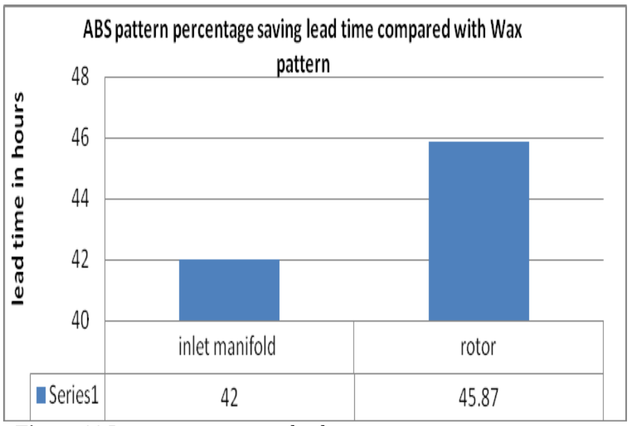


Figure 11 Percentage saving in lead time

So the value of lead time for RP is lesser than the wax pattern, here percentage saving in lead time as compare with Wax pattern are 42% for inlet manifold and 45.87% for rotor.

6. Conclusions

The patterns produced with FDM process shows 58% of Inlet manifold and 54.13% of Rotor reduction in lead times as compared to Wax patterns. So the lead time for RP is lesser than the Wax pattern, because of this percentage saving in lead time as compare with Wax pattern are 42% for inlet manifold and 45.87% for rotor. The model material, support material and part build time are the most influential parameters affecting the cost in FDM RP process. With the help of the FDM for pattern making cost save the 3001 Rs for Inlet manifold ABS pattern and 5259 Rs for Rotor ABS pattern. The cost of WAX pattern making with the help of conventional investment casting method is costlier than the ABS pattern making in FDM.

The use of benefits in terms costs have proved that the adoption of RP technology is techno-economically justifiable for the Indian manufacturing industries. Rapid Prototyping have proved to be a cost-effective and time efficient approach for development of pattern making, thereby ensuring possibility for technology transfer in Indian manufacturing industries.

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References

1. D.S. Ingole., A.M. Kuthe., S.B. Thakare, A.S. Talankar, Rapid prototyping – a technology transfer approach for development of rapid tooling, Journal: rapid prototyping journal, Volume: 15, (2009) pp: 280 – 290.
2. D.S. Ingole, A.M. Kuthe. T.R. Deshmukh, Rapid prototyping for pattern making, Foundry: A journal of progressive metal casters, Vol: 5, (2009) pp: 53 – 55.
3. P. Duverlie, J. M. Castelain, Cost estimation during design step: parametric method versus case based reasoning method, International Journal of Advanced Manufacturing Technology, 15(12), (1999) 895–906.
4. R.C., Creese, A. Rao, Scrap vs. Profitability. Modern Casting, August (1995), 38–41.
5. N.Hopkinson, P.Dickens, Rapid prototyping for direct manufacture", Rapid prototyping journal, Vol: 7, No. 4, (2001) pp: 197– 202.
6. Y. Song, Y. Yan, R. Zhang, D. Xu, F. Wang, Manufacture of the die of an automobile deck part based on rapid prototyping and rapid tooling technology, Journal of Materials Processing Technology 120 (2002) 237±242
7. R. G. Chougule, B. Ravi, Casting cost estimation in an integrated product and process design environment, revised paper submitted for publication in IJCIM, Dec 2006
8. B. Ravi., D. Joshi., K. Singh, Part, Tooling and Method Optimization Driven by Cast ability Analysis and Cost Model, Technical paper 68th World Foundry Congress and 56th Indian Foundry Congress, Chennai, 7-10 February 2008
9. Inlet Manifold an Alibre Design Tutorial by CDS Written by Steve Carr All Rights Reserved @by CDS 06-04-05
10. S. Feng, Y.Zhang, Conceptual process planning – a definition and functional decomposition. Proceedings of the 1999 International Mechanical Engineering Congress and Exposition, 10, (1999) pp. 97–106.
11. Y. Zhang, L. Wu, Rigid Image Registration by PSOSQP Algorithm, Advances in Digital Multimedia, 1:1(2012) 4-8.
12. M. Rezaei Rad, M. Rezaei Rad, S. Akbari, S. Abbas Taher, Using ANFIS, PSO, FCN in Cooperation with Fuzzy

Controller for MPPT of Photovoltaic Arrays, Advances in Digital Multimedia, 1:1(2012) 37-45.
13. Z. Zhang, Pattern Recognition by PSOSQP and Rule based System, Advances in Electrical Engineering Systems, 1:1(2012) 30-34.
14. Y. Zhang, L. Wu, Tabu Search Particle Swarm Optimization used in Cluster Analysis, Journal of Science, 1:1(2012) 6-12.
15. Y. Zhang, L. Wu, A Robust Hybrid Restarted Simulated Annealing Particle Swarm Optimization Technique, Advances in Computer Science and its Applications, 1:1(2012) 5-8.

Vitae

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