TECH FRONTIERS

Increasing productivity of cylinder head castings by process and layout modification in core shop: A case study

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The productivity of the casting process as a whole depends upon the productivity of each of the processes. One of the important processes is core making. The selection of type of core-making process is very important and it influences the productivity, casting cost and quality. Foundries have always been interested in improving productivity and profitability. But, over the past few years, competitive pressure and general industrial conditions have reinforced metal casters resolve to refine current processes and

METAL casting is unique among metal forming processes for a variety of reasons. Perhaps the most obvious is the array of moulding and casting processes available that are capable of producing complex components in any metal, ranging in weight from less than a gram to single parts weighing several hundred tonnes.

Earlier, iron castings used to be cast

to develop new technologies that improve productivity and reduce costs. One area foundries look into to improve process efficiencies and cost savings is the Core Making Process.

Production of sand cores is a complex process filled with technical challenges that can often delay the production, create scrap, rework, and increase the overall cost of a finished casting. As casting geometries are becoming more and more challenging in their designs, the demand for intricate and high quality sand cores will also continue to increase

directly from the blast furnace. Liquid iron from a blast furnace contains around 4%C and up to 2%Si, together with other chemical elements derived from the ore and other constituents of the furnace charge. The presence of so much dissolved carbon etc lowers the melt point of the iron from 1536°C (pure iron) to a eutectic temperature of about 1150°C, ensuring blast furnace iron is fully liquid and highly fluid at temperatures around 1200°C. When the iron solidifies, most of the carbon is thrown out of solution in the form either of graphite or of iron carbide (Fe_3C) depending on the composition of the iron, the rate of cooling from liquid to solid, and the presence of nucleants. If the carbon is precipitated as flake graphite, the casting is called grey iron, because the fractured surface has a dull grey appearance due to the presence of about 12% by volume of graphite (Foseco Handbook).

The properties of grey iron castings are affected by their chemical composition and the cooling rate of the casting, which is influenced by the section thickness and shape of the casting. With the widespread acceptance of SI units, there has been a convergence of national specifications for grey cast iron based on minimum tensile strength measured in N/mm^2 on a test piece machined from a separately cast 30 mm diameter bar, corresponding to a relevant wall thickness of 15 mm. There is no requirement in terms of composition and the foundryman is free to make a choice based on the requirements of the particular casting.

As with most other industries, the body of knowledge in metal casting has doubled over the last 10 years. The task of reviewing such an extensive amount of knowledge, information, and documenting the same involving various branches of manufacturing industry is almost impossible.

The properties of grey iron depend on the size, amount and distribution of the graphite flakes and on the structure of the metal matrix.

Functional advantages

Beyond the rapidly emerging technologies that are keeping metal casting in the forefront of the metal forming industry, casting processes have inherent advantages that have long been accepted by the design engineer and metal parts users. In terms of component design, casting offers the greatest extent of flexibility of any metal forming process. The casting process is ideal because it permits the formation of streamlined, intricate, integral parts of strength and rigidity obtained in no other method of fabrication.

The freedom of design offered through the metal casting process allows the designer to accomplish several tasks simultaneously. These include the following:

- Designing both internal and external contours independently to almost any requirement.
- Placing metal in exact locations where it is needed for rigidity, wear, corrosion, or maximum endurance under dynamic stress.
- Producing a complex part as a single, dependable unit.
- Achieving an attractive appearance.
- ***Rapid transition to finished product***: The casting process involves pouring of molten metal into a cavity that is close to the final dimensions of the finished component; therefore, it is the most direct and simplest metal forming method available.
- ***Suiting shape and size to function:*** Metal castings weighing from less than an ounce to hundreds of tonnes, in almost any shape or degree of complexity, can be produced. If a pattern can be made for the part, it can be cast. The flexibility of metal casting, particularly sand moulding, is so wide that it permits the use of difficult design techniques, such as undercuts and curved, reflex contours that are not possible in other high-production processes.
- ***Placement of metal for maximum effectiveness:*** The optimum amount of metal can be placed in the best location for maximum strength, wear resistance, or the enhancement of other properties of the finished part. This, together with the ability to core out unstressed sections, can result in appreciable weight savings.
- ***Optimal appearance:*** Because shape is not restricted to the assembly of pre-

formed pieces, as in welding processes, or governed by the limitations of forging or stamping, casting process encourages development of attractive, more readily marketable designs.

- ***Complex parts as an integral unit:*** The inherent design freedom of metal casting allows the designer to combine what would otherwise be several parts of a fabrication into a single, intricate casting. This is significant when exact alignment must be held, as in high-speed machinery, machine tool parts, or engine end plates and housings that carry and rotate shafts. Combined construction reduces the number of joints and the possibility of oil or water leakage.
- ***Improved dependability:*** The use of good casting design principles, together with periodic determination of mechanical properties of test bars cast from the molten metal, ensures a high degree of reproducibility and dependability in metal castings that is not as practical with other production methods. The functional advantages that metal castings offer and that are required by the designer must be balanced with the economic benefits that the customer demands.

RELEVANCE FOR CORE MAKING

For foundries to stay profitable while meeting these new environmental regulations and increasing customer demands, it is essential that the core making process is optimised to maintain tighter process control while eliminating sources of wasted time and money.

No longer can world-class quality and reproducibility be achieved in casting production without total control of the core making activity. The benefits of automatic dressing, coating and assembly of cores are widely accepted by all major foundries throughout the world.

Core making is central to metal casting. It gives industry the edge that no other metalworking industry has: the ability to form external and internal contours, shapes, cavities, and passageways in one operation. Thus, the importance of producing high-quality cores efficiently and inexpensively cannot be underestimated.

Generally, the foundry industry suffers from poor quality and productivity due to the large number of process parameters, combined with lower penetration of manufacturing automation, and shortage of skilled workers compared to other industries.

A core is a shaped body, usually made of sand, which forms the interior part of the casting. In metal casting, the mould provides a space for the molten metal to go, while the core keeps the metal from filling the entire space.

Cores allow to incorporate holes in the design, but these holes do not have to be limited to the see-through kind found in a length of pipe. Cores can take on a variety of angles and shapes, and more than one can be used per casting. Sometimes, an assembly of cores is constructed to create a web of internal passageways and chambers. This complex use of cores helps reduce the customer's inventory and avoids extra machining cost, which improved safety and quality.

An organisation's profit can be increased with the increase of overall casting manufacturing productivity. In today's environment of the foundry industry, reducing manufacturing cost by better or improved productivity and quality through innovative ideas is becoming compulsory for every foundry..

Jia Zhenyuan et al (2009) mention the results of the designed facility layout system in cylinder liner production line show that the designed lean facility layout system can effectively enhance the production efficiency and improve the efficiency of equipments.

To produce cavities within the casting – such as for liquid cooling in engine blocks and cylinder heads – negative forms are used to produce cores. Usually sand-moulded cores are inserted into the casting box after removal of the pattern. Whenever possible, designs are made to avoid the use of cores, due to the additional setup time and thus higher cost.

REQUIREMENT OF CORES

There are seven requirements for cores:

- ***Green strength:*** In the green condition there must be adequate strength for handling.
- In the hardened state it must be strong enough to handle the forces of casting; therefore the compression strength should be 100 to 300 psi (0.69 to 2.07 MPa).
- ***Permeability*** must be very high to allow escape of gases.
- ***Friability:*** As the casting or moulding cools the core must be weak enough to break down as the material shrinks. Moreover, they must be easy to remove during shakeout.
- Good refractoriness is required as the core is usually surrounded by hot metal during casting or moulding.
- A smooth surface finish.
- Low or minimum gas content. Minimum generation of gases during metal pouring.

RESEARCH ISSUES

With the initial study the following problems were identified in the core cell.

Manual process

Almost all processes are performed manually after the cores are manufactured from the core machines. Hence for operating all activities skilled workers are required. The manual operations are more time-consuming and have more limitations in operations.

For production of cylinder head or cylinder block casting, core making and core assembly are the major processes. Mostly the loading of raw material to fins removing/trimming, core dressing etc are performed manually.

Problem of ergonomics

In most of the foundries ergonomic problems persist because of manual operations. The layout is not in proper flow and hence there are more non-productive movements for assembly of the cores. The surrounding environment contains dust particles mixed in air. These result in less efficiency of workers.

Ineffective layout

The plant layout has significant impact on productivity and production volume. Proper plant layout utilising plant space and machinery leads to higher productivity and higher efficiency of workers.

Material movement problem

Improper plant layout gives rise to the problem in material movement resulting in waste of time and rise in production cost.

Input material storage

On a daily basis shell sandbags are fed to all the machines manually and then as per requirement the operators take and load shell sand to his shell sand machine magazine.

Shell core making process

This process itself is costly in comparison with other processes like cold box system and/or the no-bake process. Hence it is an absolute necessity to find the better option which will enhance productivity and reduce the cost.

FINDINGS OF LITERATURE SURVEY

- It is essential that the core making process is optimised to maintain tighter process control while eliminating sources of wasted time and money.
- It is an absolute necessity to develop low-cost automation for core handling, core dressing, venting, and assembly.
- Robust processes are required to get consistent quality, reducing waste, and increasing productivity.
- Lean principle technique and SLP (systematic layout planning) to be applied for effective layout.
- Process like cold box core making instead of shell core making process can be tried to for enhanced productivity with minimum cost.
- Use of string diagram/spaghetti diagram to reduce the travel time of independent core transfer for assembly.
- Innovative ideas through KAIZEN principles for improving productivity and quality.
- For increasing the productivity foundries in western countries are mostly using robots for drilling/venting, core dressing, like operations.
- Online core assembly is also becoming familiar for getting the single flow layout for better productivity

CYLINDER HEAD PRODUCTION AND CORE MAKING PROCESS FLOW

Table1 and **Figure1** give the data for cylinder head production for FY2013-14 to FY2015-16 and monthly production figures for FY16-17.

Core making process flow and identification of bottleneck

Current core making process

Types of cores used for cylinder head cavity:

- Intake – Shell process
- Exhaust – Shell process
- Water jacket – Shell process
- Top cover core – Cold box process
- Bottom cover core – Cold box process

The existing process

Core making: The engine cylinder head has the three cavities inside the head for fuel entry and exhaust and the water passage for engine cooling (**Figure2**). These passages are namely the Intake and exhaust ports and the water passage for cooling.

For excellent cleanliness inside the passages, the prime requirement is good quality core in terms of profile, surface finish, and dimensional accuracy.

As regards the existing process, these cores are manufactured in shell process

Table1: Cylinder head production FY13-14 to FY15-16 and April16-March17

Month	J head	S head	J 4 head	T head	E head	Other	E FT	E PT	A H2	A H3	M T 4	I head	Total
Avg.13-14	3500	2500	0	3100	240								9340
Avg 14-15	4274	4300	864	3417	286								13140
Avg 15-16	4710	5105	1455	3398	292	47	403	793	18	30	30		15227
Apr16	5277	3092	680	3359	176		1348	1144		26	38		15140
May16	5652	3792	1250	2268	182		892	1436		146	58		15676
Jun16	6867	4908	680	24	277		1782	1000		74	24		15636
Jul16	6305	4350	500	2864	734		1600	656		46	0		17055
Aug16	3444	4400	1154	4048	1111		10	3204	29	41			17441
Sep16	5976	1072	1350	3788	293		1584	1424					15487
Oct16	6332	2172		2693	1113	41	958	1738		80			15127
Nov16	6324	2456	132	3411	689		0	2644					15656
Dec16	6861	4312	862	1565	247		956	1240		474			16517
Jan17	3742	6956	545	2783	0		474	294		150			14944
Feb17	4208	4960	741	3213		247	151	1616		264			15400
Mar17	4580	3992	996	2941			1526	1228	76	82		164	15585
Avg 16-17	**5464**	**3872**	**808**	**2746**	**482**	**144**	**940**	**1469**	**53**	**138**	**30**	**164**	**15805**

Figure1: Monthly cylinder head production, April 2016-March 2017

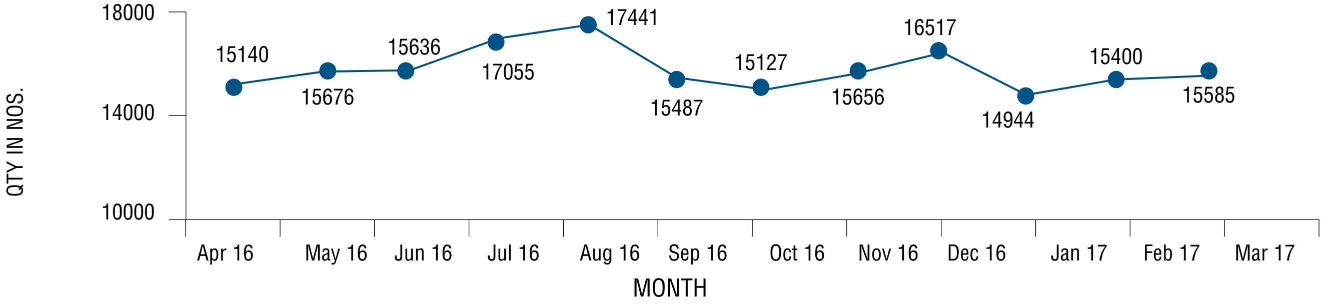
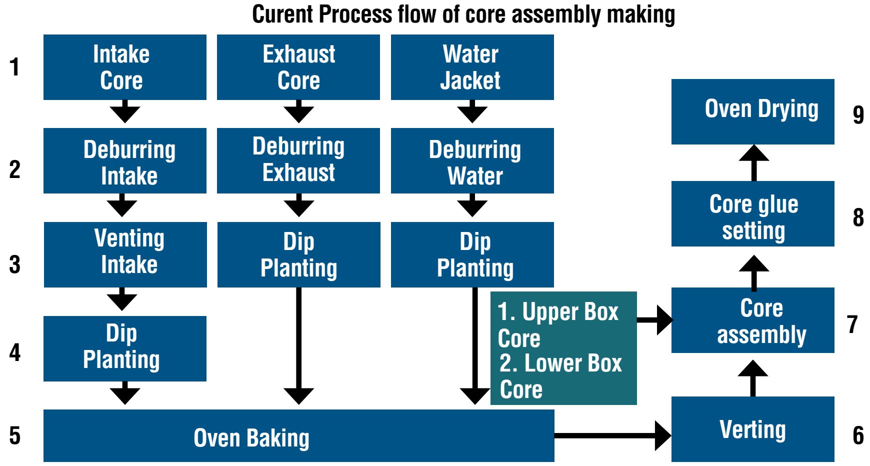


Figure2: Existing core making process flow for cylinder head core assembly



wherein the resin-coated sand is shooted in the heated core box to get the desired shape, compact and dense core.

After the cores are manufactured, the deburring operation is required for all the cores after they are taken out from the core boxes, also known as parting line flash removal. The shooting gate marks and ejection marks are to be removed from the cores. All these come under deburring operation. No excessive grinding is allowed since excessive grinding will deteriorate the core surface and in turn the casting surface finish. The same process of deburring is applied to the intake, exhaust and water jacket cores.

PROCESS PARAMETER SETTING

Temperature setting

Temperature setting is one of the important parameter for getting the right temperature for heating the shell core after the shooting in the sand in the shell core box. The basic requirement is that core should be cured to correct temperature so that it gives enough strength to withstand the molten metal turbulence and pressure. So also it should break when the casting is made.

Normal temperature setting is between 210°c to 300°c. However, prime requirement is that core should be cured enough to give almost brown colour for its correct properties. Uncured core may cure during the process and may emit more gases in the casting process.

Hence, to set and validate, numerous number of trials have to be taken to validate the temperature and the curing time setting. Also, it depends on the size, shape and intricacy of the core.

During the casting, core is surrounded by the molten metal and subject to severe thermal condition; hence proper core venting provision should be given to get the defect-free casting. Generally, vent holes are made by piercing the sand core with vent wire from core print side. These holes can be reached by near core skin for better permeability.

Cores are vented to specific locations as per the design requirements to escape the gases generated during the pouring and solidification of metal. The venting can be either manual with drill machines or with special purpose machines for more accurate location and depth.

Gas evolution is extremely important to avoid the gas-related defects in the castings. The size of the vent and from where it is required to exit is the part of design.

Figure3: Core making: Existing process flow with operation and idle time

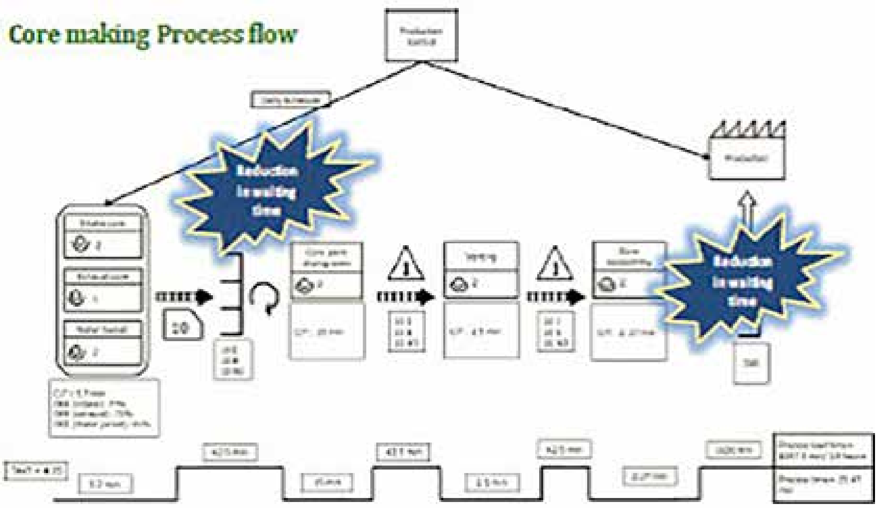
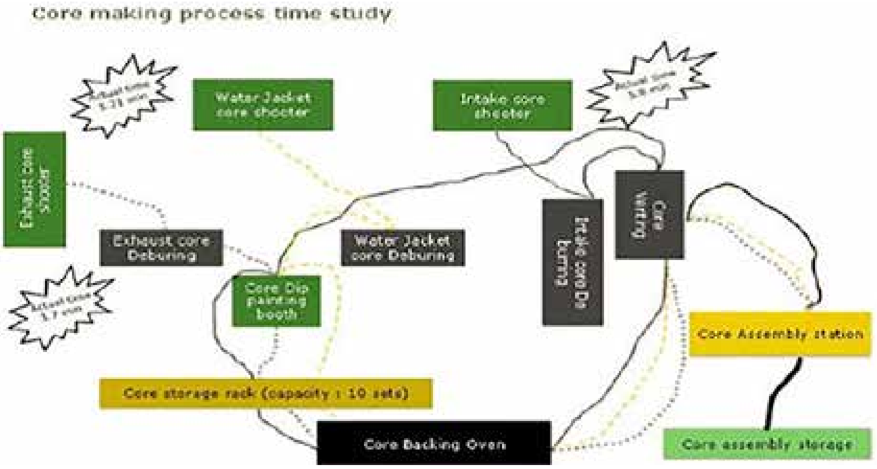


Figure4: Spaghetti to understand core making process time study



Core wash/core painting

The core is required to be painted for better surface finish of the core itself and in turn the surface finish of internal cavities of the castings. The core paint may be of water, spirit or alcohol base.

Paint viscosity is to be kept in between the 13 to 15 and core paint thickness is around 150 to 250 microns.

The top and bottom tray core are basically used for better sizing and profile of both top and bottom side of the cylinder head casting. These cores are manufactured in cold box process. The core pack is assembled and put the same in moulding pocket.

Ultimately the core assembly is dried in the oven after the gluing of individual core setting and ready to go for placing in the moulding and pouring.

Core baking

Cores are baked to develop the strength obtainable from organic binder in the core sand. During the baking, moisture is driven off first, holding the core temperature to around 1500 C and then other binder changes chemically. Core baking is normally done in the oven, may be batch type oven or the continuous core oven. Both the type of furnaces got the advantages and disadvantages as per the type of production. In case of mass and continuous production continuous core oven is preferred.

Proper baking of cores is essential to perform the core satisfactorily when metal is poured. Underbaked cores give much of gas and can cause variety of defects.

Baking of core is the process of hardening of core by drying out the binder at a temperature 200°C to 300°C. In the baking process the moisture is first removed and then binder changes chemically to solid.

Nut brown is required to be obtained however the dark brown colour is of over baking whereas light brown colour is the sign of underbaking.

Drying of cores increases the strength, reduces the gas evolution on metal pouring. During drying the moisture is removed by bringing the temperature of core 180°C to 240°C. The drying process is done inside the ovens at a slow rate.

Then they are brought to room temperature again slowly in order to avoid cracking and crumbling of the surface.

Core making process flow with production and assembly time

When the existing process flow was studied, it was observed that considering the waiting time for assembly curing time and shell core making process total process time observed 25.47 minutes and process lead time is 1147.5 minutes.

Value stream mapping has supporting methods that are often used in Lean environments to analyse and design flows at the system level (across multiple processes). In this value stream mapping, there are three major segments:

- Information flow
- Material flow
- Lead time ladder.

In analysing value stream maps, realisation dawned that some may have been created primarily as heuristic tools to teach Lean concept. It seemed as if the process improvement teams had focused on the method as the end, rather than how to use the method as a means to achieve the desired results as an end. The details were overwhelming.

Core making: Sub-processes time study

Table2: Intake core making: Activity time study

Process	Min	Sec
Cleaning of core box	0	18
Core making	4	8
1st venting	0	27
2nd venting	0	49
Dipping	0	8
Total	4	110
Total time (sec)	**350**	
Total time (min)	**5.83**	

Table3: Exhaust core making: Activity time study

Process	Min	Sec
Cleaning of core box	0	20
Core making	2	58
Dipping	0	10
Total	2	88
Total time (sec)	**208**	
Total time (min)	**3.46**	

Table4: Water jacket core making: Activity time study

Process	Min	Sec
Cleaning of core box	0	50
Core making	3	40
De burring/coat application	0	36
Dipping	0	7
Total	3	133
Total time (sec)	**313**	
Total time (min)	**5.22**	

Core making process individual core time study with Spaghetti diagram

Value stream mapping is a Lean-management method for analysing the current state and designing a future state for the series of events that take a product or service from its beginning to the customer. At Toyota, it is known as 'material and information flow mapping.' It can be applied to any value chain.

Two key matrices associated with value stream mapping are value adding times and non-value adding times. Non-value adding time is called waste or muda.

Spaghetti is a visual representation using a continuous flow line tracing the path of an item or activity.

The continuous flow line enables process teams to identify redundancies in the work flow and opportunities to expedite process flow.

Creating a Spaghetti diagram is the creation of actual flow. The keyword ACTUAL, is what it should be or perceived to be. It is a snapshot in time so it may not include all what–if and special scenarios. This is one of the best tools for mapping the process.

Value stream mapping is a method of visually mapping a product's production path (materials and information) from 'door to door.' Value stream mapping can serve as a starting point to help management, engineers, production associates, schedulers, suppliers, and customers recognise waste and identify its causes. The process includes physically mapping of 'current state' while also focusing on where one wants to be, or 'future state' blueprint, which can serve as the foundation for other Lean improvement strategies.

A value stream is all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product:

- The production flow from raw material into the arms of the customer
- The design flow from concept to launch.

Taking a value stream perspective means working on the big picture, not just individual processes, and improving the whole, not just optimising the parts.

Within the production flow, the movement of material through the factory is the flow that usually comes to mind. But there is another flow of information that tells each process what to make or do next. You must map both of these flows.

Value stream mapping can be a communication tool, a business planning tool, and a tool to manage the change process. The first step is drawing the current state, which is done by gathering information on the shop-floor. This provides the information needed to map a future state. The final step is to prepare and begin actively using an implementation plan that describes, on one page, how you plan to achieve the future state.

It was observed after the spaghetti diagram and assembly flow process study that there were a lot of unnecessary movements and handling of the individual cores as well as the partial assembly of the cores. Operator inconveniences are more as regards the core trolley and movements of the cores for further assembly sequence.

Figure5: Core making sub processes analysis

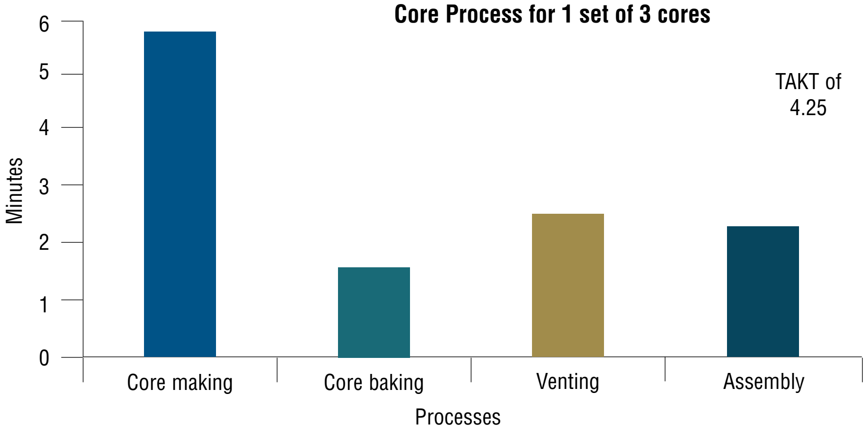


Table5: Core making sub-process analysis

Process	Batch of 10	Min/set of cores
Core making	57	5.7
Core baking	15	1.5
Venting	3	0.3
Assembly	22.7	2.27

Figure6: TAKT time calculations

$$\text{TAKT} = \frac{\text{Productive time available}}{\text{Number of required units}} = \frac{22\text{hrs}*60}{250} = 5.28$$

$$250 \text{ good castings}*\ 1.23 \text{ rejection} = 307.5 \text{ units} = {\sim}310 \text{ units}$$

$$\text{Effective TAKT} = \frac{22 + 60}{310} = 4.25$$

Quality rejection: 23% (considering all 3 stages).

Core making sub-processes analysis

Studies on all types of cores of cylinder head reveals that the cycle time of cold box cores that is top cover and bottom cover are comparatively less than that of shell cores.

The shell cores – Intake, Exhaust, and Water Jacket – are treated as complicated cores. However, the major reason for shell core cycle time being more is basic requirement of heating of the core boxes as part of process itself.

LAYOUT

A plant layout study is an engineering study to analyse different physical configurations for a manufacturing plant. It is also known as Facilities Planning and Layout. Plant layout is a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipment, and all other supporting services along with the design of best structure to contain all the facilities. It is nothing but the physical arrangement of industrial facilities to obtain the desired results. It involves the allocation of space, and arrangement of equipments in such a way that the overall operating cost is minimised.

Objectives of plant layout

- Streamlining the flow of material through the plant to facilitate manufacturing process.
- Maintaining high turnover of in-process inventory
- Minimising material handling and cost. Making effective utilisation of cubic space.
- Flexibility of manufacturing operations and arrangements.
- Providing employee convenience, safety and comfort. Minimising investment in equipment, minimising overall production time, and facilitating the organisational structure.

Proposed process flow of core assembly dip painting

There are five major changes in the processes.

1. Conversion of shell core process to cold box process

2. Dip painting of complete assembly instead of individual core painting

After the intake and exhaust cores are manufactured by the cold box process since there was bottleneck operation for making with shell process, the other cores are manufactured in the existing process.

Figure7: Proposed process flow of core assembly dip parining

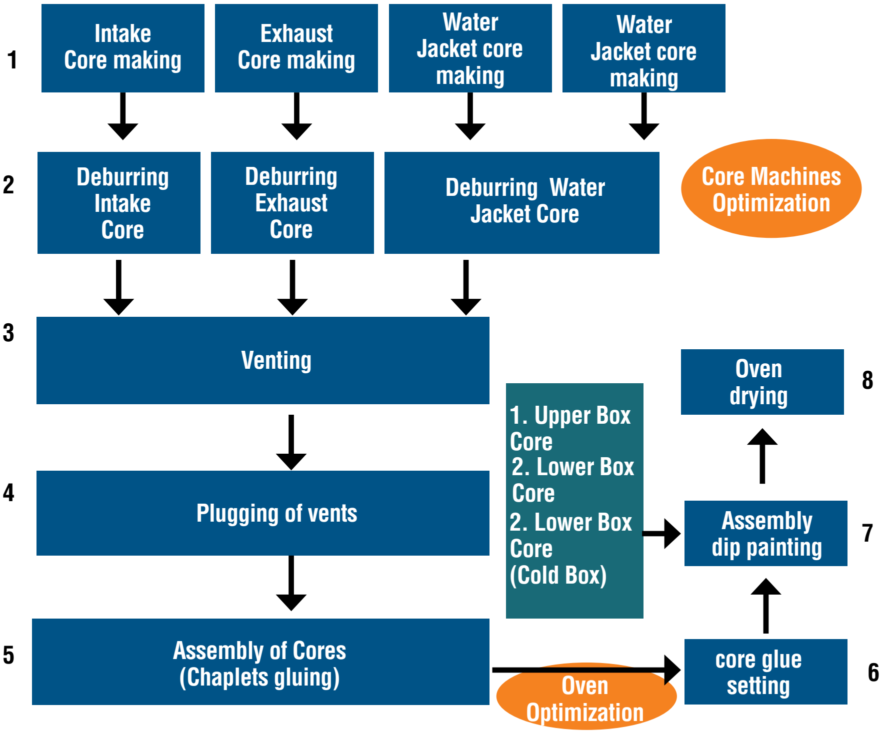
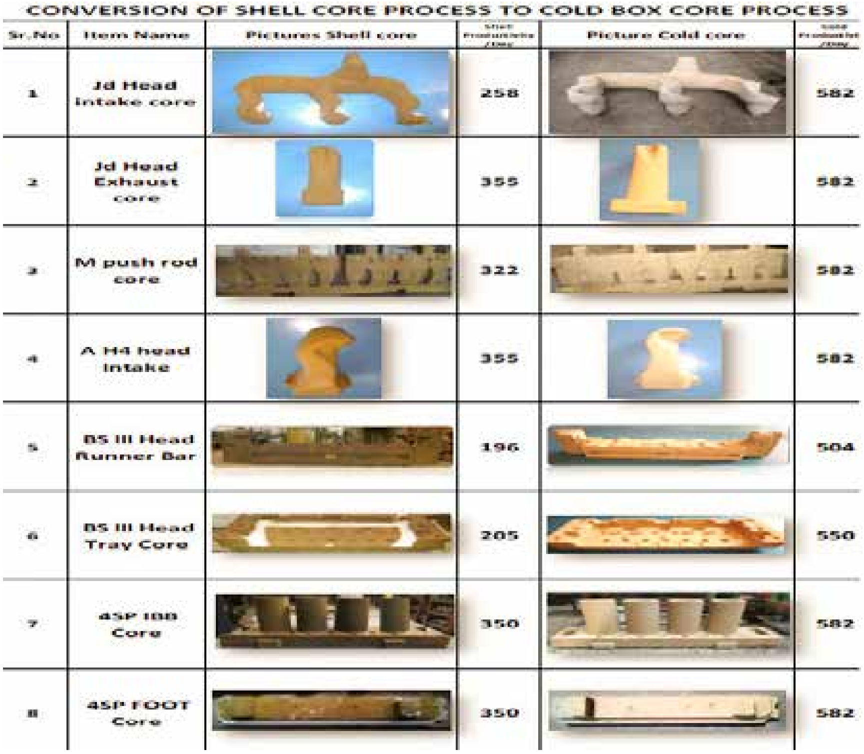


Figure8: Few examples of conversion



CONVERSION OF SHELL CORE PROCESS TO COLD BOX CORE PROCESS

Sr.No	Item Name	Pictures Shell core	Shell Production /Day	Picture Cold core	Cold Production /Day
1	Jd Head Intake core		258		582
2	Jd Head Exhaust core		355		582
3	M push rod core		322		582
4	A H4 head intake		355		582
5	BS III Head Runner Bar		196		504
6	BS III Head Tray Core		205		550
7	4SP IBB Core		350		582
8	4SP FOOT Core		350		582

Deburring of all the cores done in raw condition as earlier and venting is done as per existing process.

Since we are going for the dip painting of the whole assembly, it is very important to close the vents to prevent paint to enter and cause the gas-related defects.

All the cores are assembled in the bottom tray and the whole assembly is dip painted. The painted assembly is passed through drying oven with temperature of average of zones of 250°C. Top cover is also passed through the oven for drying. The chaplets are placed in the bottom tray before it is taken for moulding on the line.

For a medium-sized jobbing foundry the core making machines are arranged as per orders. When they get further orders the machines are arranged accordingly. There is minimal flexibility to accommodate the core boxes and hence the layout becomes rigid and fixed.

3. Proposed single direction layout for core making and assembly

Core handling

Trolleys: Special trolleys are manufactured to place the cores set in the specified place in the trolley.

The benefits of manufacturing special trolleys are:

- Inventory of the cores are kept under control since the cores are manufactured in sets as per required and available space in the trolley
- Allocated space with specific rest ensures the cores are handled with minimum damage
- Ease in taking the cores in sets for assembly of the cores in the bottom tray which is in cold box system.

This shows how we can achieve the non-touching of cores to avoid the core damages.

The way of placing the cores is to keep the numbers in control for doing the desired numbers in set for production.

The trolleys are moved as per loading pattern for assembly of the cores and

Figure9: Productivity improvement graph of shell core to cold box process conversion

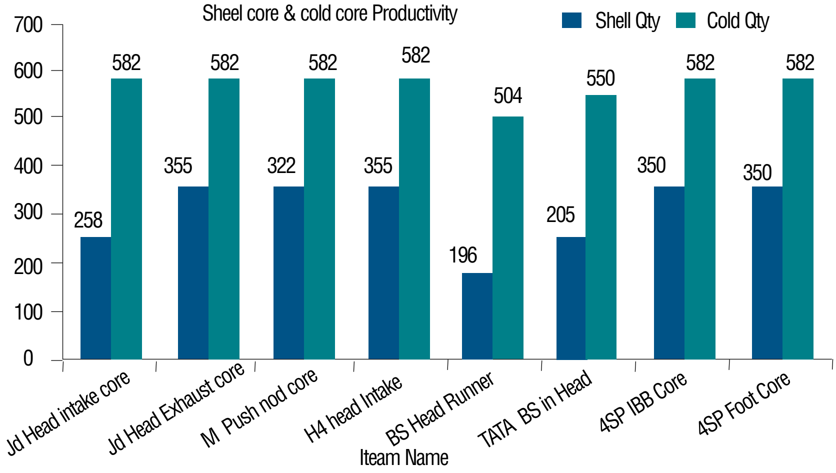


Figure10: Holding of the dipped complete assembly for dipping (manual)

Figure11: Assembly tilting for paint dropping to avoid run down and droplets

production planning to feed the assembly to the moulding line.

After the process change, the process time observed is 11.47 min and process lead time observed is 494 min against 1147.5 min.

Working for shell to cold proposal

Conversion of intake and exhaust core box of shell core to cold box core making: The core box which is utilised for shell core making is modified with back mounting plate for core box mounting.

Shooting gates are appropriately placed for proper filling of the cores. Core must be dense and properly filled with sand for proper profile.

Bush provision is made for proper shooting and gassing on the shooting plate.

The most important for getting the good core in manufacturing is ejection system.

The ejection system can be made on the magnetic rod basis or the spring-operated core ejection.

Dimensional accuracy: Dimensional variation of the cores should be minimal and hence suitable resin-coated sand or resin is used. Most important is validation of the process, wherein the checking gauge is used for 100% cores for its dimensional accuracy. It is to see that there is no difference because of the process change.

Validation: In the process of validation of the core, scratch hardness of the core is very important. The scratch hardness of the core normally to be achieved is minimum 65. The resin and hardener addition are to be maintained within the range of 0.8-1.0% and the catalyst addition of around 0.25% for getting the desired hardness.

Core assembly: After getting the bottom tray and the individual cores ready, by using the gauge the intake, exhaust,

Figure12: Single direction layout for core making

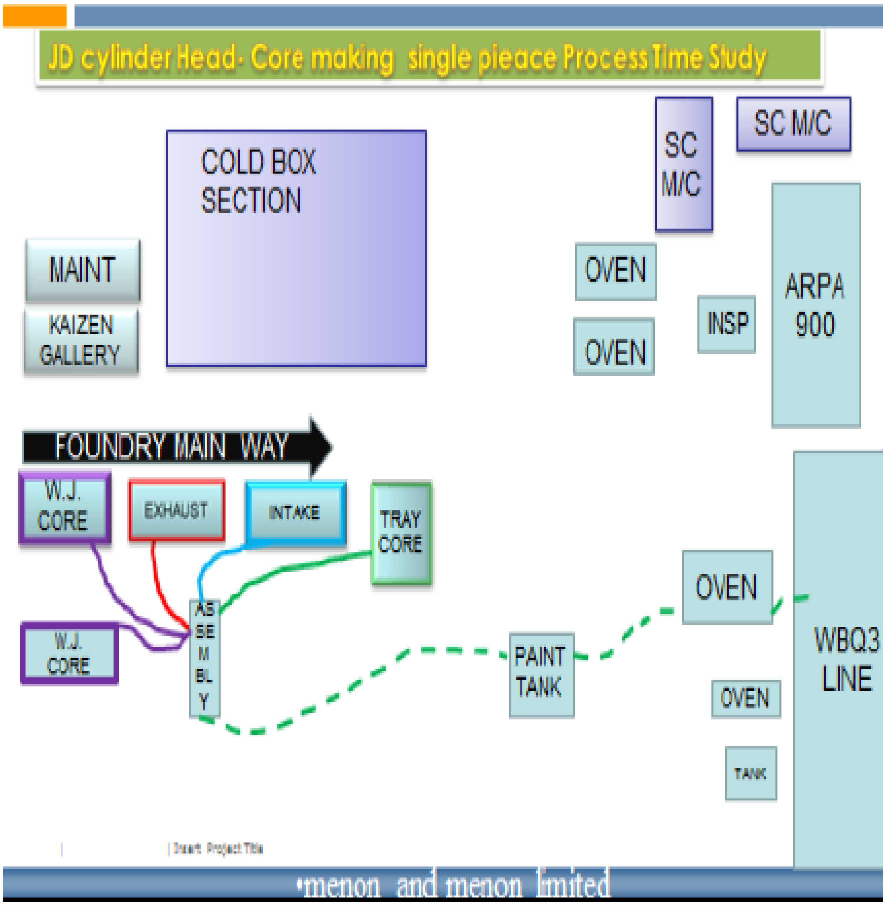


Figure13: Assembly dip painting process flowchart

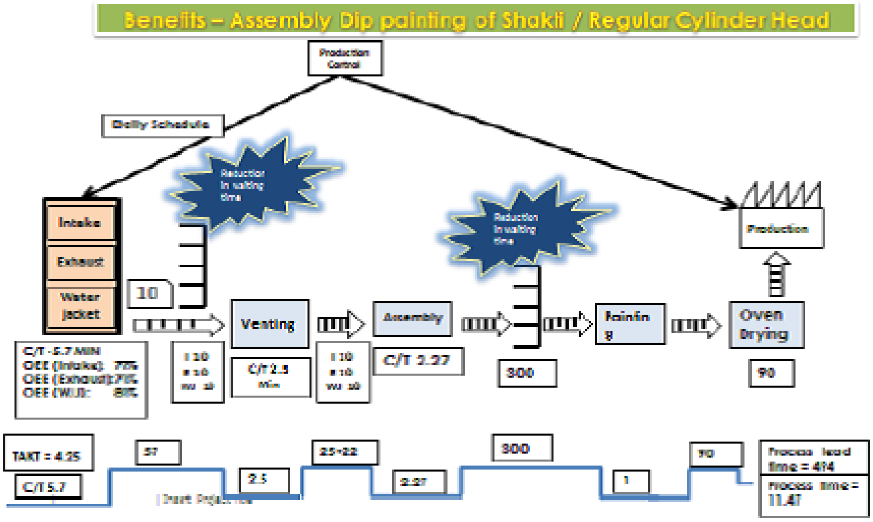


Table6: Example of shell to cold box proposal with increased quantity of cylinder head

Core Name	Current				Proposed			
	Type	Actual	Additional	Total time	Type	Actual	Additional	Total time
		Process time (min)	Time (sec)			Process time (min)	Time (sec)	
Intake core	Shell core	4.45	84.00	5.83	Cold box	2.75	84.00	4.15
Exhaust	Shell core	3.30	10.00	3.46	Cold box	2.35	10.00	2.52
Water Jacket (mchn1+mchn2)	Shell core	4.50	96.00	5.21	Shell core	3.25	0.00	3.25
Total core production in a day (numbers)	253				318			

and water jacket cores are assembled in the bottom tray. The refractory coating is applied to some specific location for avoiding the sand fusion in the internal passage.

Dip painting: After the assembly of all the intake, exhaust and water jacket cores in desired sets in bottom tray, the whole assembly is dipped for coating.

The advantages of assembly dipping are:

- Uniform coating all over the surfaces of cores since uniform viscosity of the paint
- Minimum flashes in the castings.

Figure14 shows the core assembly dipping with predetermined cycle on the semiautomatic core dipping machine.

4. Combined core boxes

Core boxes are manufactured to use the maximum capacity of cold box core making machines to get the multiple numbers in single shoot.

5. Gum used for assembly of cores

In any foundry it is always found necessary to join two or more cores together before using them for setting in mould making. The joining may be done either in warm or in cold condition. The adhesive material used for the purpose is called core gum, core joining paste, core paste, core cement, core fix, core grip, etc.

Figure14: Core assembly dipping with predetermined cycle

In general, there are two types of gums in use: (a) where bonding is given by an organic adhesive like dextrin, resinous material, glue, etc; and (b) where bonding is given by sodium silicate. The first type of gum is normally prepared inside the foundries and used within a few hours of making as the storage qualities are normally poor. These gums have basically higher gas content. The second type is normally supplied by foundry chemical manufacturers based on proprietary formulations and normally has a very long life in sealed containers. These specifications apply to silicate base core gums. Depending upon the rate of setting there are two grades of core gums – slow setting and fast setting.

Cores joined by a slow setting gum in cold condition are movable for about an hour or more to enable jigging or adjustments. Fast setting gum is required to be used when core assemblies are to be moved within about 20 minutes.

COST SAVINGS DETAILS IN POWER, MANPOWER AND INPUT MATERIAL

Table7: Cost savings details in power, manpower and input material

SI No.	**Description**	**Per day**	**Per month**	**Cost saving /day**	**Cost saving /month**	**Cost saving /annum**
A	Manpower saving	3	75	1140	28500	342000
B	**Power cost**	**Unit/day**	**Rate**	**Cost saving /day**	**Cost saving /month**	**Cost saving /annum**
1	Intake	144	6.8	979	25459	305510
2	Exhaust	144	6.8	979	25459	305510
Subtotal				**1958**	**50918**	**611021**
C	**Material cost**	**Monthly qty**	**Cost saving /head**	**Cost saving /day**	**Cost saving /month**	**Cost saving /annum**
1	Intake and exhaust core	4500	13	2249	58474	701688
Total cost saving				**5347**	**137892**	**1654709**
Total		**Monthly qty**	**Cost saving /head**	**Cost saving /month**	**Cost saving /annum**	
Total cost saving /head		**4500**	**30.91**	**139094**	**1669131**	

CONCLUSION

Productivity

Productivity of cylinder head casting manufacturing increased from 640 numbers/day to 1013 numbers/day and it is tested for producing and delivering the same consistently. **Table8** shows the numbers increased to almost 26,000 per month. If we see the production of overall cylinder heads, the productivity has increased from 16,342 numbers in April 2017 to 25,830 numbers in October 2018. That is an achievement of almost 380 numbers per day.

In **Figure15**, it can be seen that cylinder heads production and monthly heads production from April 2016 till Oct 2016 increased by almost 10,000 numbers per month.

Cost

Total cost savings of Rs16.70 lakh per year was achieved due to:

- Material consumption reduced
- Power consumption reduced
- Manpower cost reduced

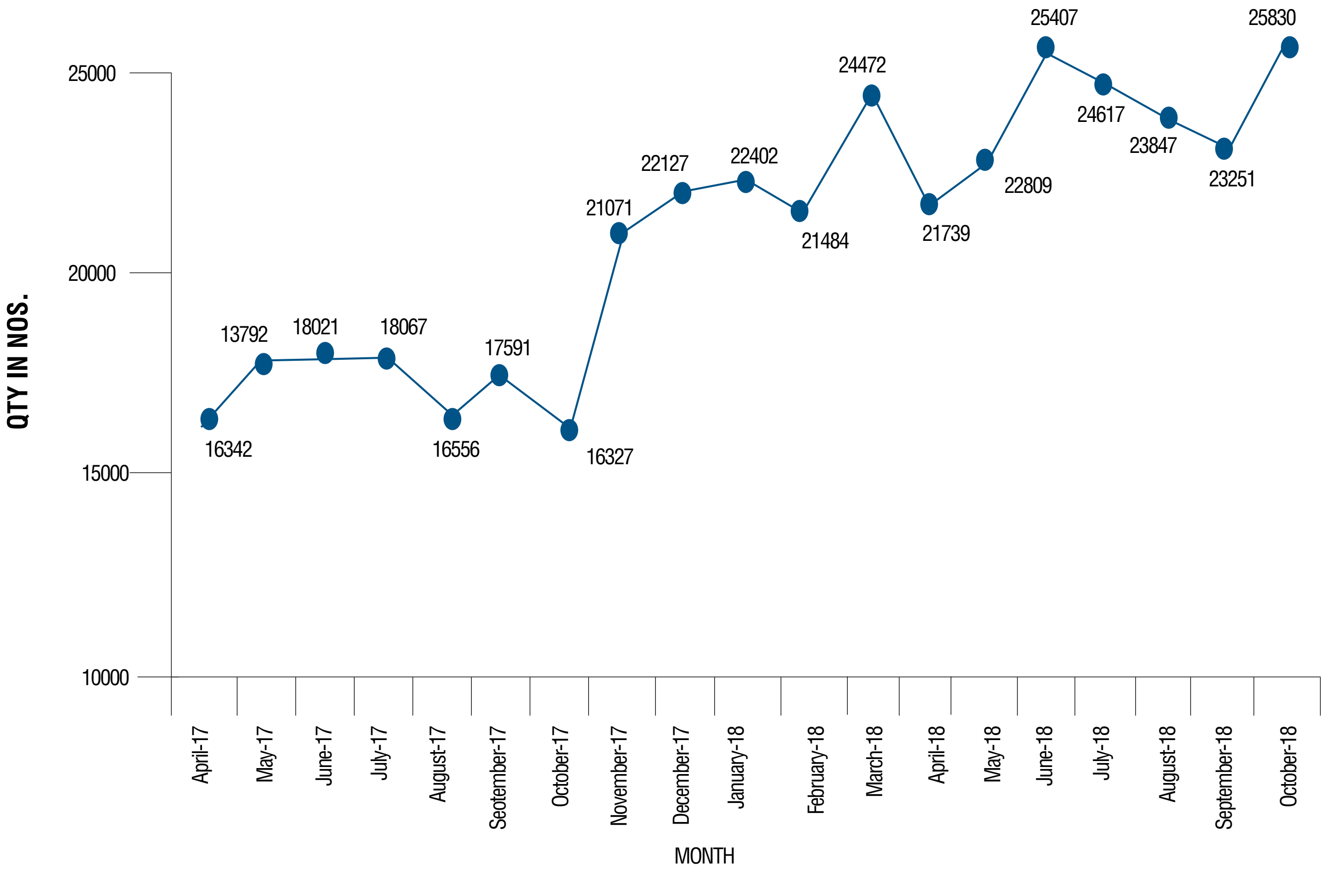
Process values by testing different parameters of each process. After the detailed study for optimising the temperature as well as the time, we can come to a very specific temperature range and time of curing for getting the desired quality of core so that it should not be over-baked and at the same time, it should not be uncured so that it carries the defects like blow holes in the casting. With this study, it is proved that it is always beneficial to change the shell core making process to cold set core making process. The shell core making consumes the huge energy to heat and compaction of the core. Along with the saving of Rs1.40 lakh per month the following benefits are achieved.

- ***Productivity of cylinder heads*** enhanced. Production run trial is taken for more than 1000 numbers per day and process is set accordingly
- ***Improved casting surface finish:*** With the comparator method Ra value achieved is between 12 and 25 micron against the existing 50 microns
- ***Clean internal cavities:*** With a whole assembly dip painting of uniform coating, we found clean internal passage
- ***No grinding marks on internal areas:*** Less flashes hence less or minimal grinding/fettling, hence no grinding marks on the internal passage of the castings
- ***Improvement in delivery performance:*** As the productivity numbers are reached, the delivery of daily around 850 nos. achieved for dispatches
- Proper layout in core assembly flow in a cell after core assembly, due to which there is comparatively less handling and good quality cores are only fed to the moulding line and hence less rejection
- Reduction in extra effort at fettling (head internal cavity cleaning)
- Reduction in core assembly handling
- Reduction in core rejection, as individual core handling is reduced
- Operator fatigue is reduced because of less handling.

Table8: Month-wise cylinder head production April 2017-October 2018

Month	JD head	S head	J4 head	T head	E head	E FT	E PT	A H2	A H3	A H4	I head	Total
Apr17	7858	3100	1357	2626	0	50	1034	0	170	73	58	16342
May17	6091	2116	1522	3983	586	1168	1490		836			17792
Jun17	6375	2984	0	4309	1315	1450	1200	0	216	42	130	18021
Jul17	6458	3796	721	4915	339	852	384	0	406	32	56	18067
Aug17	7996	992	562	5177	177	132	682	0	610	174	154	16656
Sep17	8994	2380	754	4035	596	166	92		146	408	20	17591
Oct17	7574	1840	1309	3780	520	174	16	56	756	68	234	16327
Nov17	6777	4512	2160	5174	738	212	524	412	98	298	166	21071
Dec17	6900	5344	2180	5081	1202	586				544	290	22127
Jan18	6691	6968	2566	4542	649	588					368	22402
Feb18	8018	6340	2297	2974	650						822	21484
Mar18	7661	7986	3131	4005	333	0		378			560	24477
Apr18	7431	6264	2926	3365	319			290		482	662	21739
May18	8062	5920	2289	4168	691			570		812	210	22809
Jun18	11092	5880	944	4740	997			510		706	538	25407
Jul18	10847	4256	653	5201	989					1488	1158	24617
Aug18	10695	4964	636	4533	188			898	126	642	1150	23847
Sep18	9136	5516	2412	3682	192	0	0	526	0	744	1022	23251
Oct18	9982	6308	2080	4847	665			618		310	1020	25830
Avg 17-18	7283	4030	1547	4217	592	489	678	121	405	205	260	19363

Figure15: Trend of enhancing the productivity after July 2016



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