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5 Cs of Investment Casting Foundries in Rajkot Cluster – An Industrial Survey

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Abstract

Investment casting is very well-known manufacturing process for producing relatively thin and multifarious industrial components with high dimensional tolerances as well as admirable surface finish. Investment casting process is further comprised of sub-processes including pattern making, shell making, dewaxing, shell backing, melting and pouring. These sub-processes are usually followed by heat treatment, finishing as well as testing & measurement of castings. Investment castings are employed in many industrial sectors including aerospace, automobile, bio-medical, chemical, defense, etc. Overall market size of investment castings in world is nearly 12.15 billion USD and growing at a rate of 2.8% every year. India is among the top five investment casting producers in the world, and produces nearly 4% (considering value of castings) of global market. Rajkot (home town of authors) is one of largest clusters of investment casting in India, and has nearly 175 investment casting foundries that is almost 30% of investment casting foundries of India.

An industrial survey of nearly 25% of investment casting foundries of Rajkot cluster has been conducted in the year 2019-20 in order to get better insight related to 5 Cs (Capacity; Capability; Competency; Concerns; Challenges) of investment casting foundries located in the cluster. Specific set of questionnaires was design for the survey to address 5 Cs of investment casting foundries of Rajkot cluster, and their inputs were recorded during the in-person survey. The industrial survey yielded in providing better insight related to 5 Cs of foundries in Rajkot cluster. It will also help investment casting producer to identify the capabilities and quality issues as well as leads to benchmarking respective foundry.

Keywords: Investment casting, Rajkot cluster, Capacity, Capability, Competency, Concerns, Challenges

1. Overview

Overall journey of typical investment casting process is believed to be started from jewelry and idol making, and it has been traced to ancient days. Investment casting process is then gradually matured, and its applications are extended in manufacturing of industrial castings employed in many industrial sectors including automobile, aerospace, bio-medical, chemical, defense, marine, machine tool, etc. The journey of investment casting process is illustrated in Figure 1.The applications of investment casting are also extended to many commercial alloys including Aluminum, Cobalt, Copper, Nickel, Stainless Steel and Titanium in comparison with its limited capability of making castings for only non-ferrous alloys involving Copper, Gold, and Silver in its early days.

Fig.1. Journey of Investment Casting Process – Ancient to Contemporary [3]

Typical industrial investment casting comprised of different sub-processes including pattern making (making of disposable wax pattern by injecting molten wax into the metallic die with the help of wax injection machine); pattern assembly (assembly of wax patterns, and integral parts of feeding as well as gating system); shell making (construction of ceramic shell around the wax pattern by dipping assembled pattern tree into slurry comprises of coarse and fine sand); dewaxing (ejection of wax from shell to create cavity for pouring); shell baking (firing of the ceramic shell to improve hot strength of the ceramic shell, and prepare it for pouring); melting & pouring (melting of alloy using suitable means of heating, and pour the molten alloy into baked shell). These sub-processes are followed by knock out, finishing, measurement, and testing of castings.

2. Prospective of Investment Casting

Global market size of investment casting is estimated to over 12.15 billion USD, and still growing at an average rate of 2.8% [1]. Overall sales of investment casting in different countries are illustrated in Figure 2 [2]. North America is one of the largest manufacturers of investment castings in world with nearly 39% of total sales across world. North America is followed by China, and United Kingdom, with nearly 23% and 11% respectively of total sales in world. Overall sales of investment casting are mainly distributed into three categories including high valued (aerospace, defense, biomedical, etc.), automobile as well as general engineering (agricultural, chemical, etc.). The distribution related to sales of North America, UK and China are shown in Figure 3[2]. It is observed that 90% sales of investment castings in UK is related to high valued castings while it is 77% in North America, and followed by 25% in China.

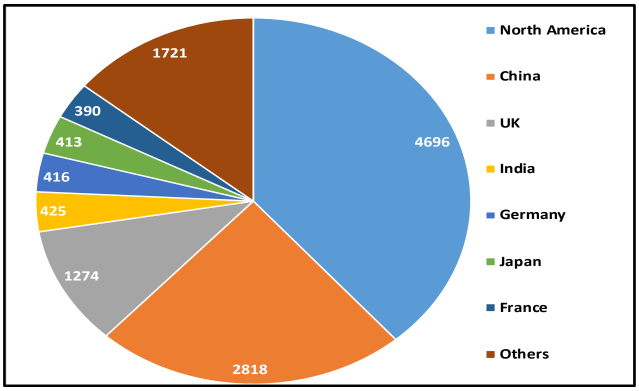


Fig. 2. Overall sales of investment casting foundries in different countries (in million USD) [2]

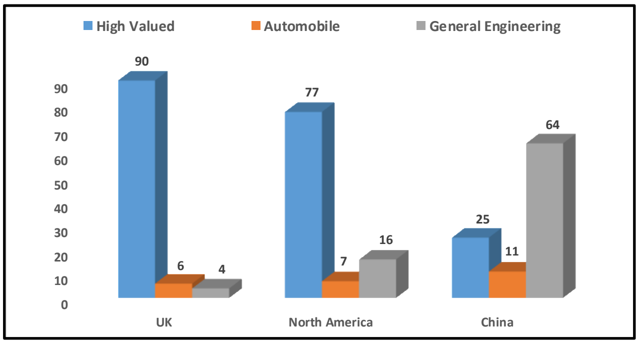


Fig. 3. Distribution of overall sales for investment castings (in percentage of sales)[2]

India is amongst top 5 investment casting producers in world, and produces nearly 4% of total castings produced in world. India mainly produces investment castings related to general engineering (80% of total production), automobile (with 14%), and high valued castings (with 6%) [2]. These industrial castings are mainly produced in various foundry clusters including Ahmedabad, Belgaum, Coimbatore, Howrah, Kolhapur, Ludhiana and Rajkot. However, most of the investment casting foundries (nearly 25% of total foundries) of India are located in Rajkot cluster.

To obtain a better insight regarding 5 Cs (capacity, capability, competency, concerns and challenges) of investment casting foundries, an industrial survey was carried out in Rajkot. This is an important manufacturing hub in Gujarat State, with more than 10000 engineering units, including nearly 800 foundry units. The major focus is automobile parts, as well as diesel engine castings, which are exported to Europe, Middle East, and Southeast Asia. More than 175 are investment casting foundries, making Rajkot the largest such cluster in India (the country is estimated to have about 700 investment casting foundries). Most of the investment casting foundries here manufacture pump, valve and automotive castings; only a few (less than 15% of the foundries) focuses on high-quality and high-value markets of aerospace, defense and bio-medical castings. The survey was also meant to enable comparison with similar foundries in other cluster and countries. Detailed methodology adopted for an industrial survey, and its outcome are discussed in next section.

3. Methodology of Survey

The survey covered 42 investment casting foundries (list of foundries is not disclosed due to confidentiality agreement with foundries), representing nearly one fourth of those in Rajkot. A questionnaire was designed for this survey, which is in five parts. The first section (capacity) is an overview of the foundry capacity, and included questions related to production capacity (tonnage per

year), utilization (percentage), and proportion of domestic sales and exports (by weight and by value). It also represented key factors including quality, quantity, delivery and value addition. The second section (capability) covered the capability of foundries in terms of range of metals, casting weight, critical limits (such as minimum wall thickness), and types of customers (application sectors). It also covered the details about manufacturing process, including type of equipment, level of automation, and typical process parameters (such as shell baking temperature).
The third section (competency) focuses on competency of foundry related to availability of in-house testing facilities (e.g., wax testing, ceramic testing, mechanical testing, metallurgical testing and non-destructive testing). The fourth section (concerns) is designed to extract information based on adoption of any OEM specific guidelines or published standards for assuring quality in respective foundry. It also provides information on awareness of foundry about implementing recent technologies including 3D modeling, casting simulation, data acquisition, and Internet of Things (IoT). The last section (challenges) of the questionnaire solicited information related to casting quality, including major defects encountered, and their frequency of occurrence. The survey was administered by taking appointment from the top management of the foundry, meeting the nominated person, and filling the questionnaire over discussion. The data was collected during

4. Results

The survey provided several valuable insights of the prevailing scenario of investment casting foundries in Rajkot cluster, which may be considered to be a fair reflection of the status of this industry in India. The results of the survey (Table 1) related to three aspects: capacity, capability and challenges, are highlighted here.

Table 1.
Key results of investment casting foundry survey

Foundry	Installed Capacity (MT/Y)	Utilization (%)	Export of Castings		Size of Castings (kg)		Thickness (mm)		Lead Time (Weeks)	Rejection (%)
			% of Weight	% of Value	Min	Max	Min	Max		
1	800	45	NA	NA	0.035	150	3	78	4	1.5
2	1000	90	55	65	0.035	150	3	78	4	1.5
3	1300	90	30	40	0.005	128	4	70	3	6
4	600	75	30	40	0.005	80	5	60	3	5
5	1100	80	75	75	0.020	170	3	80	9	3
6	600	60	40	35	0.025	80	2	100	7	3.5
7	1500	70	30	35	0.100	105	3	80	4	3.5
8	720	70	NA	NA	0.050	125	3	70	4	4
9	800	85	40	60	0.050	120	3	30	8	6
10	950	50	NA	NA	0.008	80	2	30	5	7
11	400	90	20	30	0.100	150	5	20	3	12
12	400	75	1	1	0.050	200	3	80	3	5
13	550	60	10	NA	0.015	150	4	NA	NA	1
14	600	50	5	5	0.005	230	2	80	4	0.3
15	600	90	30	35	0.500	90	12	80	3.5	4
16	1200	80	30	NA	0.010	300	5	28	7	4
17	70	90	NA	NA	0.030	48	2	45	2	3
18	210	80	NA	NA	0.005	9	2	100	3	2
19	360	83	10	8	0.010	350	4	40	4	3
20	360	100	NA	NA	0.015	16	3.5	55	3	3
21	4200	60	50	65	0.250	280	3	100	7	3
22	950	75	30	38	0.050	128	3	85	8	7
23	720	25	90	NA	0.010	40	2	70	9	5
24	1310	80	10	20	0.013	155	3	50	6	5
25	1400	50	10	10	0.050	70	2	45	6	2
26	1500	65	5	7	0.150	150	2.5	75	8	4
27	1200	80	5	5	0.050	100	10	75	5	5
28	1600	75	80	80	0.100	150	3	60	13	6
29	35	85	20	20	0.050	72	4	NA	4	4
30	490	45	NA	NA	0.080	15	4	40	1	14
31	60	70	30	40	0.005	160	3	600	3	3
32	450	75	35	40	0.020	200	3	60	5	2
33	550	80	70	70	1	350	10	100	4	3
34	1100	50	NA	NA	0.008	130	4	30	5	4.5
35	150	80	70	NA	0.050	120	3	50	7	0
36	1200	75	70	80	0.040	95	3	60	9	6
37	1200	75	70	80	0.040	95	3	60	9	6
38	1200	75	70	80	0.040	95	3	60	9	6

39	500	60	5	5	0.020	70	13	50	2	2
40	600	50	2	5	0.008	80	2	32	4	3
41	400	80	65	60	0.050	50	3	8	4	3
42	1000	85	60	65	0.050	180	2	80	5	5

4.1. Capacity

The minimum, maximum and average values of the installed capacity as well as its utilization in investment casting foundries were calculated from the data provided for each foundry. These are shown in Figure 4 and 5. The average capacity of these foundries was found to be 855 metric tonnage per year; and their average utilization was 71%. Foundries in the middle range of capacity were found to have better utilization. The data related to export of the investment castings (in terms of percentage of weight of casting exported to total weight of castings produced) was also collected and analyzed. This was found to have a wide range from 1-90 %, with the average value of 37%.The minimum and maximum values of casting exported by weight and by value are shown in Figure 6.

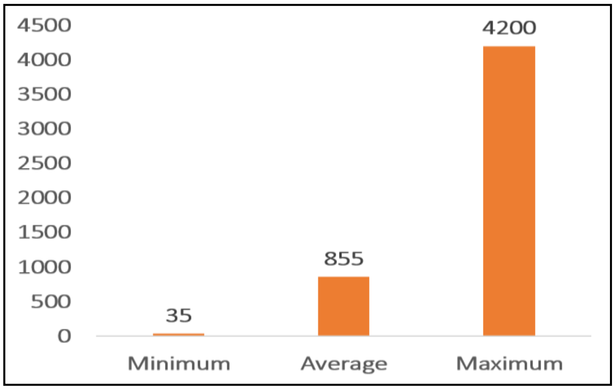


Fig. 4. Installed capacity (tonnage per year) of foundries in Rajkot cluster

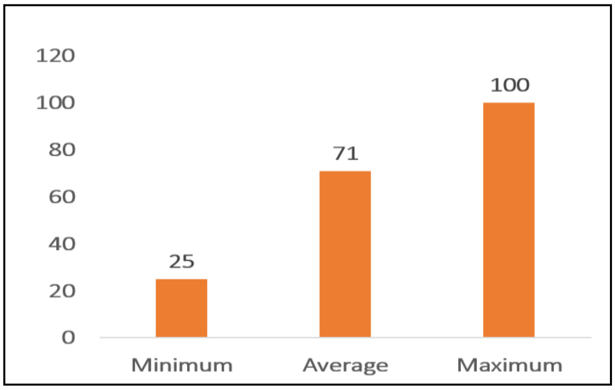


Fig. 5. Capacity utilization (tonnage per year) of foundries in Rajkot cluster

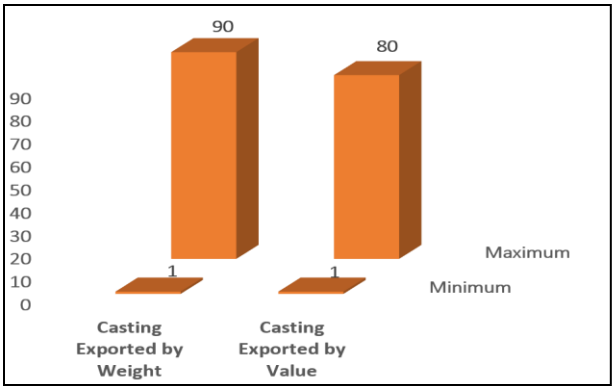


Fig. 6. Casting exports by weight and value (in percentage of total sales)

4.2. Capability

The capability in terms of casting size, wall thickness, shell thickness, lead time, types of metal handled, application sectors, a method adopted for pouring and shell baking temperature was recorded for all the investment casting foundries that participated in the survey. It was observed that typically these foundries could produce casting size from 0.005 - 350 kg. These foundries are capable of handling wall thickness from 2-600 mm. The lead time for the new order ranges from 1-13 weeks. These foundries preferred shell thickness from 2.5 - 22.5 mm with shell baking temperature from 750 – 1150 °C. The minimum and maximum values of casting size, wall thickness, lead time, shell thickness and shell baking temperature of these foundries are shown in Figure 7 and 8. It was concluded that most of these foundries manufactured stainless steel parts for the chemical and automobile sector. It was observed that most of the foundries adopted a manual pouring method for pouring molten metal into the mold.

4.3. Competency

The competency of foundries in terms of wax testing, ceramic testing, mechanical testing, metallurgical testing and non-destructive testing were collected. It was found out that only 20% of investment casting foundries that participated in the survey have all in-house testing facilities. The wax testing and ceramic testing were established by 50% and 33% of the foundries. While facilities related to mechanical (with 86% of foundries), metallurgical (76%) and non-destructive testing (69%) were available with foundries participated in the survey.

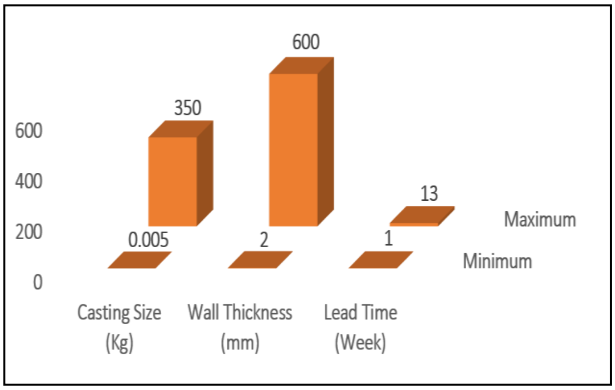


Fig. 7. Casting weight, wall thickness and lead time

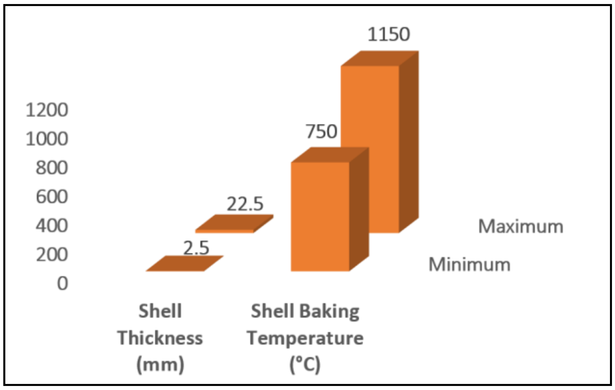


Fig. 8. Shell thickness and shell baking temperature

4.4. Concerns

The concerns related to adopting specific OEM guidelines as well as published standard for assuring quality in foundry are acquired. An intention of foundries related to awareness and implementation related to data acquisition, 3 D modeling, casting simulation as well as Internet of Things (IoT) was also noted in the survey. It was observed that all the foundries participated in the survey adopted either specific OEM guidelines or published standard (e.g. IATF 16949, AS9100) for assuring quality in foundry. More than 40% of foundries are using 3 D modeling and casting simulation packages. While nearly 20% of foundries are acquiring data from foundry, and have awareness about IoT.

4.5. Challenges

The challenges related to overall rejection percentage at the end of each sub-process and major defects in terms of dimensional, surface, internal, shape, and external were recorded. The minimum, average and maximum values of overall rejection is shown in Figure 9. It was found that minimum and maximum overall rejection stands at 0.3% and 14% respectively. However, the average overall rejection of these foundries was found at around 4%. These foundries have major rejection at shell making stage. The internal defects (~49%) and surface defects (~28%) are considered as major defects in the investment casting foundries. It was observed that shrinkage (~25%) and shell inclusions (~20%) are major internal defects, while excess metal (~15%) and cold shut (~8%) are major external defects happening in these foundries. The major defects, internal defects and external defects of the foundries are shown in Figure 10 (a), (b) and (c).

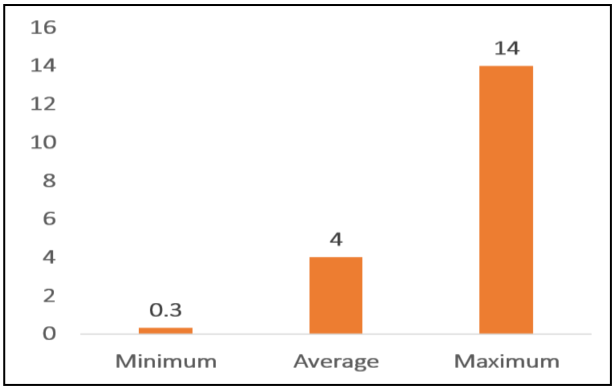
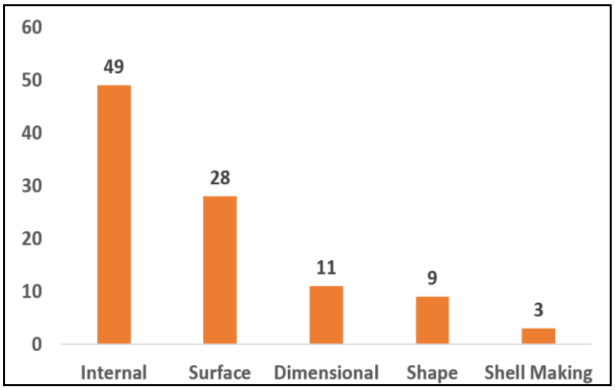
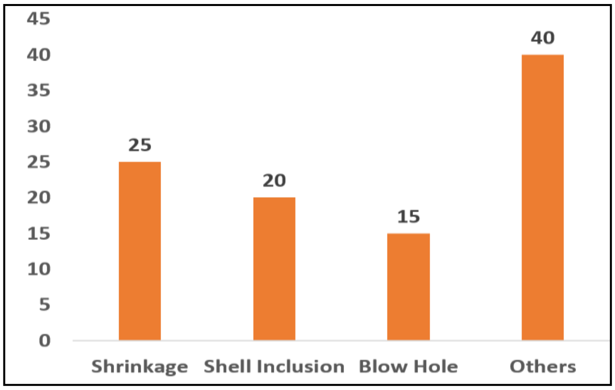


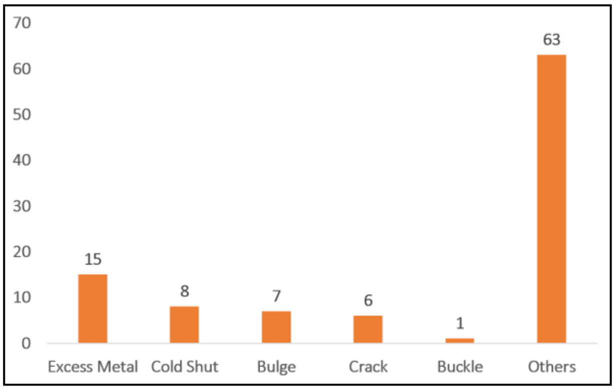
Fig. 9. Overall Rejection (in percentage of total production)

a)



b)





c)

Fig. 10 (a), (b) and (c): Major Defects (in percentage of overall rejection), Internal Defects (in percentage of major defects), External defects (in percentage of major defects)

5. Benchmark

Survey results associated with capacity, capability, competency, concerns and challenges helps in establishing existing trend (Table 2) of investment casting foundries located in Rajkot cluster. This was prepared based on the inputs received by different investment casting producers. It is observed that investment casting producer of India need to focus on capacity utilization of installed capacity and to add more values in existing produced castings. This can be achieved by producing castings of high valued alloys such as Cobalt, Haste, Nickel, Titanium required in aerospace, biomedical and defense sectors. Investment casting foundries also need to focus on introducing emerging technologies including data analytics, and casting simulation for improving quality of investment castings. It is observed that control over shell making process is essential in order to reduce overall rejection in investment casting. Existing trends help in establishing benchmark for investment casting producers as well as upcoming foundries in India.

Table 2.
Existing trend in Investment Casting Foundries of Rajkot Cluster

Section	Parameter	Existing Trend
Capacity	Capacity utilization (%)	71
	Casting exported by weight (% of total production)	90
Capability	Casting size (kg)	350
	Wall thickness of casting (mm)	2
	Shell thickness (mm)	2.5
	Lead time (week)	5
	Shell backing temperature (^{0}C)	1007
Competency	In house testing facilities	• Raw material (Wax, ceramic, alloys) testing • Destructive/Nondestructive testing
Concerns	Use of Technology	• 3-dimensional modeling • Casting simulation • Data Analytics
Challenges	Overall rejection (in percentage)	4
	Rejection (stage wise) (in percentage of overall rejection)	Shell making (39%)
	Defect (Internal) (in percentage of rejection in melting section)	Shrinkage Porosity (25%)
	Defect (External) (in percentage of rejection in melting section)	Excess Metals (15%)

This benchmark will help foundrymen located in Rajkot cluster to approximate the prominence related to capabilities of their foundries. This will also help foundries located in other clusters of India including Belgaum, Coimbatore, Howrah, Ludhiana, and Kolhapur to identify key factors that can be focused for improvement in existing industrial setup. This benchmark also helps emerging foundrymen to get an awareness about future trends as well as challenges in investment casting foundries.

6. Conclusions

The survey clearly shows that nearly one fourth of the production capacity lies unutilized. While this can be partially attributed to general trends in the manufacturing sector, it also points to the possibility of exploring new markets, especially aerospace, defense and biomedical. These however, have stringent quality standards and requirements, coupled with the reliability of supply chains. The investment casting foundries in India, hitherto focused on the low-value segments (automobile, pumps and valves), need to move up the value chain. This can be achieved by developing scientific and systematic approaches to quality assurance supported by information technology, especially process data analytics and Industrial Internet of Things. The methodology and tools must be easy to adapt in industrial foundries for use by regular engineers.

Acknowledgement

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