ALUMINIUM GDC TECH
GREAT DIE CASTING

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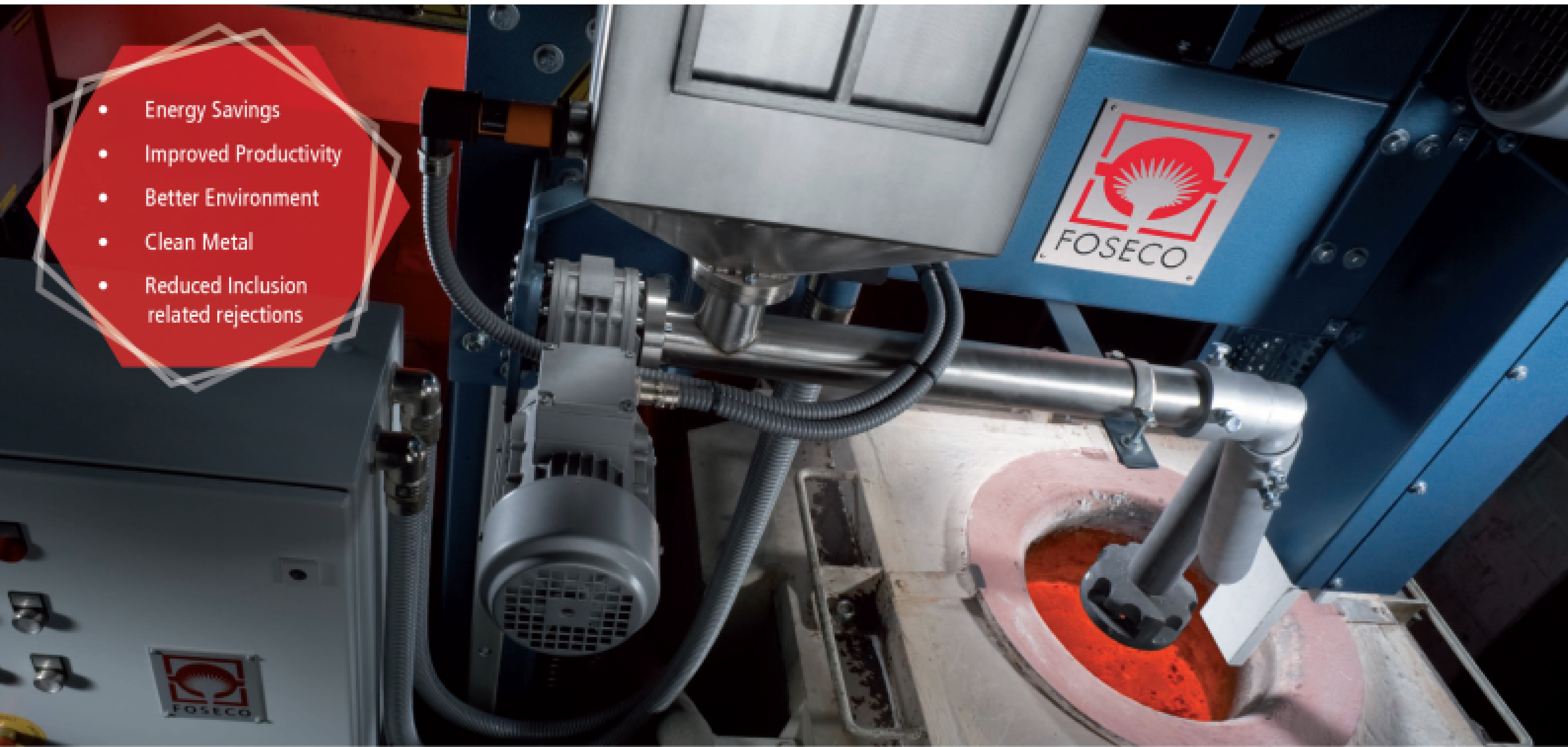

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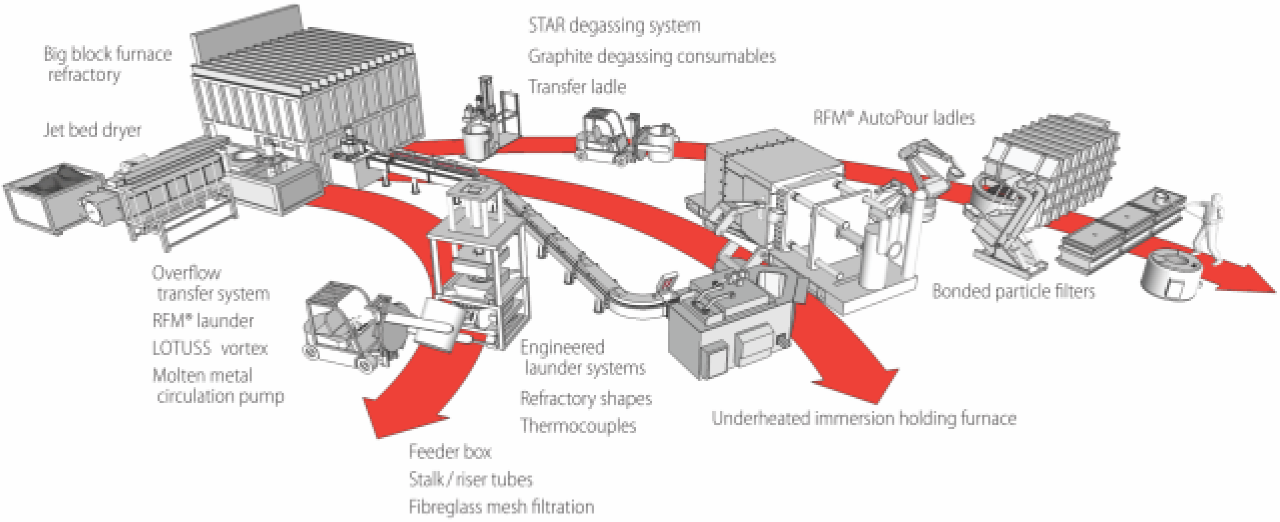

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ALUMINIUM GDC TECH GREAT DIE CASTING

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FOSECO

Developments in die coating Technology

Background

Something in the region of 40% of aluminium castings produced globally are made via the gravity diecasting (permanent mould) and low pressure diecasting processes. It has always been accepted that a major contributor to the successful manufacture of quality parts is the coating which is applied to the die surface. FOSECO has had for many years a comprehensive range of coatings which give:

- ❑ Insulation control
- ❑ Release from the die
- ❑ Encouragement to fill thin sections fully
- ❑ Control of surface finish
- ❑ Soundness (feedability)

The use of DYCOTE die coatings has been widespread in the foundry industry for more than 60 years with the traditional product range modified to satisfy specific customer requirements. The products have also evolved to reflect the change in casting requirements, however, nomajor developments have been made for some considerable period.

Over the past 5 years the market demands regarding die coatings has been changing with productivity and plant utilisation becoming more important within the foundry industry. Any interruption in production and subsequent down- time while cleaning and recoating is a major cost and inconvenience to the foundry so improvements in DYCOTE life will offer significant benefits.

This has given FOSECO the opportunity to reassess its strategy towards the DYCOTE product range.

Traditional DYCOTE die coating range

The DYCOTE die coating range can be separated into three distinct product types:

- ❑ Insulating coatings
- ❑ Heat conductive coatings
- ❑ Lubricating coatings

The insulating coating range is the largest of the three groups. These coatings help maintain metal temperature and therefore metal fluidity during the filling of the mould. The insulating characteristics of the coating will come partly from the constituents and partly from the surface roughness of the coating. The surface roughness is generated by the particle size of the refractory fillers and varies between 10 and 100 microns. In general the coarser the coating the higher the insulation effect. When selecting a die coating for each specific application there is always a compromise between surface finish of the casting and the filling of the mould cavities.

Listed below are some typical coatings taken from the FOSECO Insulating coating range.

Type of Coating	Typical Grain Size µm	Thinning Ratio	Application, Description
Base Coat			
DYCOTE D R 87	18	1:1 - 1:3	Primer, increases adhesion and thereby lifetime of the top coating
Insulating Coatings			
DYCOTE D R 787	10	1:3 - 1:5	Can be applied at higher temperature than standard coatings
DYCOTE D 39	15	1:3 - 1:5	Where excellent surface finish is essential
DYCOTE D BN 120	35	1:10 - 1:20	Coating containing boron nitride for smooth surfaces, although the coating itself has a rough surface, and long holding times
DYCOTE D 140	35	1:3 - 1:5	Mid range coating for standard applications. Coarse coatings often used for thin walled automotive castings.
DYCOTE D 7039	78	1:3 - 1:5	
DYCOTE D BN 7039	78	1:3	
DYCOTE D 34	80	1:3 - 1:5	
DYCOTE D 6 ESS	85	1:3 - 1:5	

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In certain applications it is necessary to apply conductive coatings to increase heat transfer and encourage rapid cooling. These coatings are all graphite based and can also be used for lubrication.
Below is a list of typical coatings from this range:

Heat Conductive and Lubricating Coatings	Typical Grain Size µm	Thinning Ratio	Application, Description
DYCOTE D 40		Diluted with mineral oil	Graphite/oil ingot coating
DYCOTE D 38	5	1:10	Colloidal graphite, lubricating coating for low tapers, without binder
DYCOTE D 11	10	1:10	Semi colloidal graphite, for parts with low tapers, chill coating, without binder
DYCOTE D 36	35	1:3 - 1:5	As DYCOTE D 11, however, with additional binder

All the above listed coatings are delivered in a concentrated form and have to be diluted with water, except for DYCOTE D 40, which has to be diluted with mineral oil.

Selection of die coatings
A number of factors must be taken into consideration when selecting a die coating. Firstly the section thickness of the casting. One of the main properties of a coating is its ability to aid the filling of the die. When the casting concerned has a thin section then a DYCOTE die coating with high insulation properties should be considered. Secondly there is the surface finish requirement of a casting. This is very important, however, coatings which give very good surface finish do not also give good insulation. The balance of surface finish and insulation will therefore always be a compromise. Another important factor is the geometry of the casting which can also be critical for efficient feeding. If a casting has isolated thick sections then a specific coating may be required to help directional solidification. Where a casting has small draft angles, then a coating with excellent release may be required. Finally the casting process may also influence DYCOTE die coating selection. For example low-pressure castings can be made with coatings which have different characteristics from gravity castings. By carefully selecting the DYCOTE die coating with the required features, then optimum performance can be achieved.


Figure 1: DYCOTE die coating management station

Process control
In order to achieve the optimum performance from a particular coating it is now accepted that the mixing and application of the coating is critical. To this end FOSECO have developed a DYCOTE die coating Management Station. This enables the foundry to mix the coating in ideal conditions by accurately measuring the water addition and also gives the option of pre-programmed dilution to eliminate operator error. The use of the FOSECO Carry&Mix mixer also ensures the coating is not only mixed well but is held in suspension during the working period. Cleaning of the Carry&Mix is simple and must be carried out thoroughly to avoid possible contamination with old coating. By creating a central, controlled mixing area then the preparation of the DYCOTE die coating will be given the level of importance and control which it deserves (figures 1 and 2).


Figure 2: FOSECO Carry&Mix mixer

New Developments

As productivity in foundries became ever more important over the years FOSECO were continually asked to develop new ranges of coatings which would improve die life. The original development work was carried out by FOSECO Japan. It was soon evident that by moving to a different binder and more carefully graded fillers then significant improvements could be made in die coating performance. By making these changes a range of coatings were developed equating to the current range, and sold in Japan.

A key feature in the improved performance of these products has been the final curing of the coating. The finished die is soaked for 60 minutes at 450ºC to drive off any chemically combined moisture, reducing the tendency to pick up moisture during storage. This also hardens the surface thus increasing the coating life in service.

European Experience

When the first trials were made in Europe, using the Japanese developed products, it soon became clear that these very fine coatings were not suitable for European casting techniques. Problems with mould filling were experienced and it was found that a coarser range of Long Life DYCOTES die coating were required for the European market. The European product range to date includes;

DYCOTE	Description
DYCOTE 1450	General purpose coating.
DYCOTE 2040	Coarser version of DYCOTE 2050 - for thinner walled gravity die applications such as cylinder heads.
DYCOTE 2050	Successful for automotive castings.
DYCOTE 3950	Excellent for low pressure wheel production
DYCOTE 3975	Good surface finish, excellent release.

Application

- Best results are achieved with dilution rates of around 1 : 3
- Spray on to the die at 200 - 250ºC
- To achieve the optimum life time of the Long Life DYCOTE the die has to be cured at 450ºC for just over one hour

Advantages of Long Life DYCOTE die coatings

- Improved Productivity - Dies run for longer and so the frequency of stopping production to change to a newly coated die is reduced.
- A reduction in scrap on start up of a newly coated die. It is common when a newly coated die is first cast that the temperature profile may not be correct. Shrinkage or mis-running sometimes results. Again the less frequently a newly coated die is introduced, the fewer problems are created.
- Reduction in frequency of coating leads to a reduction in labour required in die preparation.
- As the Long Life DYCOTE die coating is tougher and more wear resistant then the die will run longer at the optimum thickness and condition of the coating, resulting in better quality castings.
- With the special composition of Long Life DYCOTE die coatings there is less likelihood of settling and segregation during mixing.
- Reduction in frequency of die cleaning will result in less die wear, improved die life and consistent casting definition.
- A lower frequency of die cleaning means a reduction in cleaning consumables and less DYCOTE die coating being consumed.
- Foundries will traditionally touch up the coating on the die to extend the coating life, without removing and recoating. Again the amount of touching up required will be far lower with Long Life DYCOTE die coating.

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FOSECO

Case Studies

Europe
In the following table a selection of castings produced throughout Europe using various DYCOTE die coating products are shown.

Casting	LLDYCOTE	Dilution	Spray temp	Curing	Performance
Suspension arm	DYCOTE 2050	1:3	200ºC	400ºC	12 shifts
Cylinder head	DYCOTE 2040	1:3	200ºC	300ºC for 3 hours	3 days
Wheel - Customer A	DYCOTE 3950	1:5	300ºC	None	10 shifts
Wheel - Customer B	DYCOTE 3950	1:5	300ºC	None	4 shifts
Wheel - Customer C	DYCOTE 3950	1:5	300ºC	None	Double life.
Housing	DYCOTE 1450	1:3	225ºC	None	5 shifts

Conclusion
The developments in DYCOTE die coatings have now given diecasting foundries a wider and more sophisticated range of products from which to choose. The products need to be able to perform such that they satisfy the requirements placed on the industry by casting designers and buyers. By careful product selection, preparation and application better performance can be achieved with subsequent improvements in casting quality, consistency, finish and productivity.

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Hon. Prime Minister, Mr. Narendra Modi held a meeting with economists, leading business leaders and policy makers.

GDC Tech Associate Mr. Bharat Gite, Managing Director & CEO, Taural India Pvt. Ltd. participated in meeting & presented his views and suggestions on, Make In India, facilities, for MSME and Need of Emphasis on Decentralisation and Vocational Training (Apprenticeship)

Details can published in the next issue.

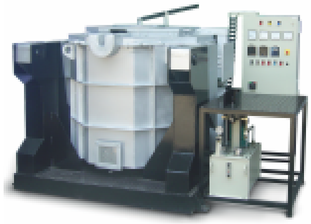
ALUMINIUM FURNACES

ENERGY SYSTECH

Electrical Furnaces

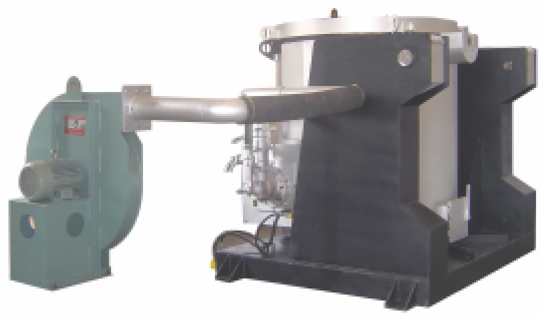

Stationary Furnace


Inner View


Tilting Furnace

Fuel Fired Furnace


Manual Tilting Furnace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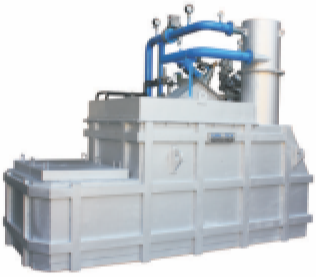
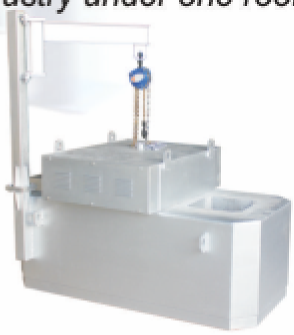


Melting Cum Holding

Electrical Holding (Crucible)



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Statistical Techniques for Industry

Pramod Gajare – Consultant. Email: pramodgajare2013@gmail.com

Specific cases in context of process, Part III

Learning Objectives

- Situation where the standard control charts are not convenient
- Concept and method for Group control chart
- Advantages and limitations of modified control limits
- Understanding the concepts through practical example

Situation where standard control charts are not convenient

In industry we often come across the situation where the same part is produced from multiple sources. The typical examples are as below.

- A multi-spindle machine producing same part
- A fixture for machining multiple parts at a time
- Same part machined on number of machines

These processes are also called as multiple stream processes. A multiple stream process (MSP) is a process in which data at any point of time consists of measurements from several individual sources or streams. MSP has some certain characteristics as below.

- When the process is in control, response of all the sources or streams is assumed to be very similar to each other.
- It is possible to monitor and adjust each of the streams individually or in small groups.

For MSP there are several possibilities of control methods, with their positive and negative points.

- The first possibility is to have a separate control chart for each stream. When there are large numbers of streams this option is not practical as plotting and maintaining the charts is difficult. Even if a single chart with same scale is plotted for all the streams, the variation for each stream can be compared; still a sizable amount of work is required for this.
- When the output of all streams is highly correlated, then the control chart for only one stream is adequate. However such situations are very rare. Hence this method can be used for such specific cases only.

- The most commonly occurring situation is that all the streams are only moderately correlated, where monitoring of only one stream is not appropriate. For monitoring of all the streams the Group Control Charts are useful.

Concept and method for Group Control Chart

Since multiple streams are involved in this process the total variation of MSP can be as shown in equation 24.01.

$$\sigma^2_{MSP} = \sigma^2_{Stream\,1} + \sigma^2_{Stream\,2} + \ldots\ldots + \sigma^2_{Stream\,n} + \sigma^2_{Measurement\ Error} + \sigma^2_{Material} + \sigma^2_{Temperature} + \sigma^2_{Operator} + \sigma^2_{Others}$$

.....eq.: 24.01

Since the process is carried out simultaneously at all the streams, the occurrence of assignable causes for variation is possible for all the elements shown in the above equation. However occurrences of these assignable causes may not be simultaneous for all the elements. There are at least two types of situations possible for occurrence of the assignable causes.

1)Shift from the target value for output from one stream or from some of the streams.

2)Shift from the target value for output from all the streams.

In the first case one will try to find out the assignable cause that had impact on output from one stream or impact on output from the some streams. Only the affected streams need to be analyzed in this case.

For the second case the focus will be on finding the assignable cause that has effect on all the streams. One example of such assignable cause is change in raw material batch.

For establishing a group control chart, the sampling scheme is same as that used for having a separate control chart for each stream. Samples from each stream are taken for measurement in a short period of time. **This is repeated until about 20 to 25 such groups of samples are taken.**

In the mean chart only the highest and lowest values of averages (X bar) observed at any time period from all the streams are plotted. Each plotted point is identified on the chart by the number of the stream/streams from which the sample is produced. All the highest points are connected by a line. Similarly all the lowest points are connected by a line. For any particular sample if the highest value is below the upper control limit (UCL), the other values from that sample are necessarily below the UCL. Similarly if the lowest value is above the lower control limit (LCL), the other values from that sample are above the LCL.

In the range chart only the highest value of range (R bar) observed at any time period from all the streams is plotted. Each plotted point is identified on the chart by the number of the stream/streams from which the sample is produced. All the highest points are connected by a line.

Any changes while the process is running must be marked suitably on the control chart and also to be recorded as "event log". This helps to keep track of the occurrences of assignable causes and actions taken on them.

Rules for the out of control situation

The rules are as those applied for the standard Shewhart control charts can not be applied for group control charts. Close watch on the stream numbers that are identified on the chart is important for understanding out of control situation. Following are some guidelines

- When any point on mean chart or range crosses the control limit, the process is out of control.
- The run tests as applied for standard control charts are not applicable for the group control charts. However if for all the streams the points show continuous shift away from the average, it is an indication of presence of some assignable cause like change in raw material batch that affects all the streams.
- If any stream is continuously showing the largest value or the lowest value, then it is a signal that stream behaving differently than the other streams.

Specific analysis for that stream or group of streams is required for finding out the assignable cause and actions for removing the same.

The various calculations involved are as shown below.

Calculations for mean chart

The centerline is placed at the "Process Mean" which is denoted by X double bar.

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \overline{X}_3 + \cdots + \overline{X}_k}{k} = \sum_{k=1}^{k} \overline{X}_j/k,$$

... eq.: 24.02

Where,

k = number of samples taken of size n.

Xj = the mean of j^{th} sample

Control limits for Mean chart

Upper Control Limit = X Double Bar +A2R Bar

...eq.: 24.03

Lower Control limit = X Double Bar -A2R Bar

...eq.: 24.04

Calculations for range chart

The individual range of each sample (**R**$_i$) is calculated and the average range(**$\overline{R}$**)obtained from the individual sample ranges using following equation.

$$\overline{R} = \sum_{i=1}^{k} R_i/k,$$

...eq.: 24.05

Where,

k=the number of sample sizes n. Then,

$$\sigma = \overline{R}/d_n \text{ or } \overline{R}/d_2$$

...eq.: 24.06

Where,
d_n or d_2 = Hartley's constant

Control limits for Range chart

Upper Control Limit = D4 R bar ...eq.: 24.07
Lower Control Limit = D3 R bar ...eq.: 24.08

Advantages of Group Control Chart

The advantages of using a group control chart are listed below.

- The work involved in plotting is reduced substantially.
- Since the presentation of all the information is compact in single chart, the interpretation can be done at ease.
- It is easy to find out, whether a particular stream or some streams are showing consistently high or low values on mean or range chart. If practically there is no difference among the streams, one can be sure that all the streams are performing at the same level.

Limitations of Group Control Chart

There are few limitations about the group control charts.

- The averages and the spreads of all the streams must be similar to each other. For example, if there are eight machines producing a same part in which three machines have better capability than the others, then the group control chart can not be applied to the eight machines together. Two separate charts are required; one for the three machines and another for the balance five machines.

- When the samples are taken, it is necessary to take samples from all the streams. This is possible when the numbers of streams are less; say up to 10. When the numbers of streams are large, as that in packaging or filling processes, the group control charts are not practical.

Example of same part produced on four machines

An illustrative example will be useful to understand the application of Group control chart. Although about 20 to 25 groups of observations are required to construct group control chart, only 15 groups are used in this illustration considering the space limitations.

A same part is produced on four machines, for which flange diameter 52.15 +/- 0.25 mm is a critical characteristic. In this case it is natural to expect that the production from all four machines put together must be within the specification limits. Every hour sample from each machine is measured for this diameter. For each machine parts from five consecutive cycles are measured. The data collected from 8.00 AM to 22.00 PM is shown in table 24.01. The calculated values of X bar and range for each sample is also shown in this table.

The highest and lowest means and also the highest range for each group are shown in Table 24.02.

Various calculations are as below.
For sample size n = 5, the values of various constants are:
dn or d2 = 2.326
D3 = 0
D4 = 2.11
A2 = 0.58

Calculations for group mean chart

X double bar = 52.1507 mm
Upper Control Limit = X Double Bar +A2RBar
UCL = 52.216 mm
Lower Control limit = X Double Bar -A2RBar
LCL = 52.086 mm

Calculations for group range chart

R bar = 0.1123 mm
Upper Control Limit = D4 R bar
UCL = 0.237 mm
Lower Control Limit = D3 R bar
LCL = 0 mm

Capability indices of this process

σ = R bar/ d2
σ = 0.0483 mm
Cp = 1.726
Cpku = 1.721 and Cpkl = 1.730
Hence; Cpk = 1.721

The group control charts for mean and range plotted based on above calculations are shown in Figure 24.01 and Figure 24.02. Now let us examine these charts for the probable signals. As a rule the range chart is to be analyzed first, followed by the mean chart.

Observations on group range chart.

- All the points are within the control limits. The process is in control.
- The highest ranges for observation numbers 2, 3,5,8,9,10,11,12 and 15 are for machine No. 3. For nine times this machine shows the highest values. The variation i.e. spread for this machine appears to be more as compared to other machines.

Observations on group mean chart.

- All the points are within the control limits. The process is in control.
- The highest means for observation numbers 1,3,4,8,12,13,14 and 15 are for machine No. 3. For eight times this machine shows the highest values. The machine No. 3 appears to be operating on higher side compared to other machines.
- The lowest means for observation numbers 1,2,4,6,8,13 and 15 are for machine No. 4. Similarly the observation numbers 3, 5, 8,11,12,13 and 15 are for machine No. 1. For seven times these two machines show the lowest values. These two machines appear to be operating on lower side compared to other machines.

Conclusions based on observations on the charts.

The above observations lead to following conclusions.

- The first action can be for machine No. 3 to find out the assignable causes for higher spread compared to other machines.
- The adjusting of the means for machine No. 3 can be done after the variation for this machine is reduced.
- At this stage any action may not be required on machine No. 1 and No. 4. These may be showing repetitive lowest values of means because machine No. 3 is operating on higher side.

Specific analysis for confirmation of actions required.

For this analysis data for each machine is separated. For each machine separate calculations are done and the results are shown in Table 24.03.

In a single chart, the mean chart for all 4 machines is plotted. Similarly the range chart for all 4 machines is plotted in a single chart. These charts are shown in Figure 24.03 and Figure 24.04.

These charts give better clarity at a glance about the behavior of process carried out on four different machines. From these charts we can conclude following.

- For all 4 machines the variation is within their individual control limits for both mean and range chart.
- Minimum subgroup variation observed for machine No. 1 from the range chart. Also it is seen through the standard deviation of 0.0361 mm.
- Maximum subgroup variation observed for machine No. 3 from the range chart. Also it is indicated by the standard deviation of 0.0556 mm.
- Position i.e. centering of the process is close to the target value of 52.15 in machines 1, 2 and 4. For machine No.3 it is shifted upwards to 52.163 mm.
- Process at machine No 3 is not in control, since it shows upward trend for both mean and range charts.

Thus, this specific analysis confirms that the conclusions based on group control chart are appropriate.

What we learned?

- A Multiple stream process (MSP) is a process where at any given time the data consists of measurements from several individual multiple sources.
- Individual control chart for each source is not practical for MSP. Hence in this case the best choice for controlling the process is group control chart.
- The basic requirement for group control chart is that averages and the spreads of all the streams must be similar to each other. If some streams are behaving differently than the other, then those specific streams must be controlled with a separate chart.
- For group control chart samples from each stream are taken for measurement in a short period of time.

- In group mean chart only the highest and lowest values of averages (X bar) observed at any time period from all the streams are plotted. Similarly for the group range chart only the highest value of range (R bar) observed at any time period from all the streams are plotted.
- When any point on mean chart or range crosses the control limit, the process is out of control.
- When any stream is continuously showing the largest or the lowest values, it is a signal that stream behaving differently than the other streams for which specific analysis for that stream is required for finding out the assignable cause and actions for removing the same.
- For the group control charts the run tests as applied for standard control charts are not applicable.
- The group control charts are not practical when numbers of streams are large.

Acknowledgements

- I would like to acknowledge my Guru Mr. S B Deo, who taught me 'Statistical Process Control'.

Time	X bar High	X bar Low	Range High
8.00	52.172	52.132	0.14
9.00	52.176	52.120	0.16
10.00	52.184	52.144	0.18
11.00	52.180	52.144	0.16
12.00	52.148	52.116	0.10
13.00	52.168	52.148	0.16
14.00	52.176	52.088	0.18
15.00	52.192	52.116	0.14
16.00	52.204	52.148	0.16
17.00	52.176	52.096	0.16
18.00	52.148	52.116	0.10
19.00	52.184	52.144	0.18
20.00	52.172	52.148	0.16
21.00	52.184	52.132	0.20
22.00	52.192	52.116	0.14

Table 24.02: The highest and lowest means and highest ranges of Flange thickness 52.15 +/- 0.25 mm

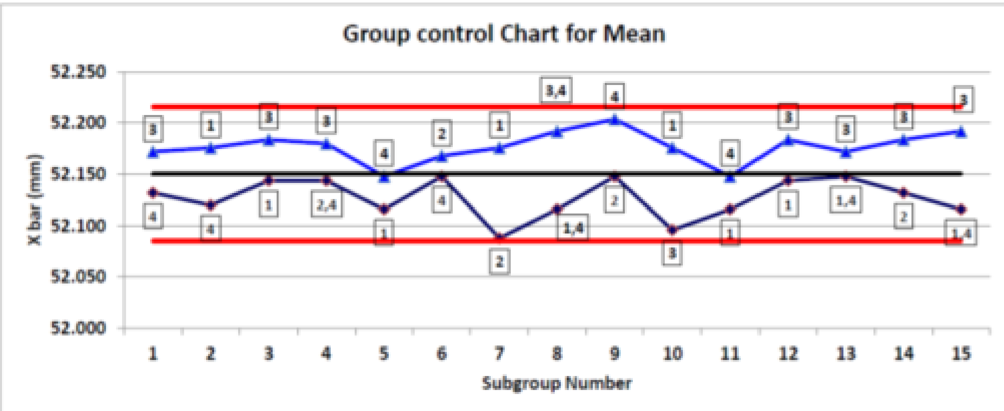

Figure 24.01: Group control chart for Mean for Flange thickness 52.15 +/- 0.25 mm

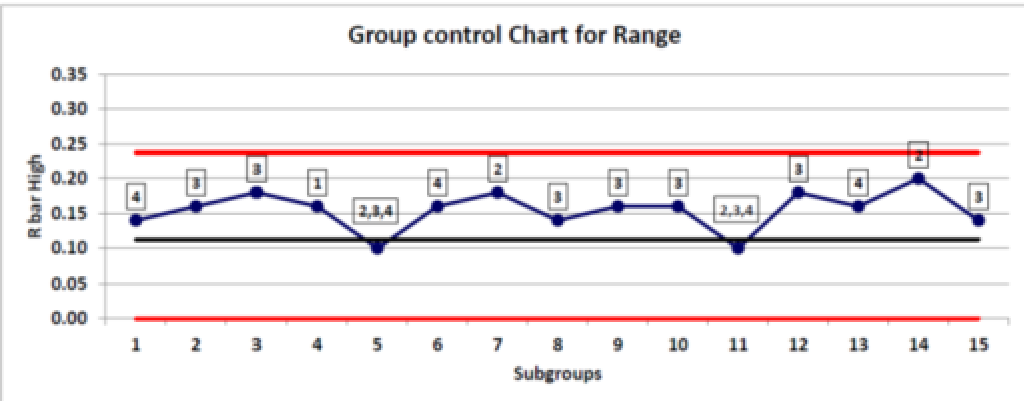

Figure 24.02: Group control chart for Range for Flange thickness 52.15 +/- 0.25 mm

Time	Machine No.	i	ii	iii	iv	v	X Bar	Range
8.00	1	52.12	52.12	52.12	52.14	52.24	52.148	0.12
	2	52.18	52.10	52.18	52.14	52.14	52.148	0.08
	3	52.12	52.24	52.22	52.12	52.16	52.172	0.12
	4	52.06	52.10	52.12	52.18	52.20	52.132	0.14
9.00	1	52.14	52.22	52.14	52.16	52.22	52.176	0.08
	2	52.14	52.12	52.08	52.20	52.20	52.148	0.12
	3	52.12	52.08	52.12	52.08	52.24	52.128	0.16
	4	52.06	52.10	52.12	52.14	52.18	52.120	0.12
10.00	1	52.16	52.12	52.10	52.16	52.18	52.144	0.08
	2	52.12	52.12	52.14	52.24	52.20	52.164	0.12
	3	52.30	52.12	52.16	52.18	52.16	52.184	0.18
	4	52.22	52.12	52.18	52.16	52.14	52.164	0.10
11.00	1	52.08	52.24	52.12	52.14	52.18	52.152	0.16
	2	52.18	52.06	52.18	52.20	52.10	52.144	0.14
	3	52.18	52.18	52.16	52.20	52.18	52.180	0.04
	4	52.08	52.20	52.06	52.18	52.20	52.144	0.14
12.00	1	52.12	52.12	52.10	52.12	52.12	52.116	0.02
	2	52.08	52.10	52.14	52.16	52.18	52.132	0.10
	3	52.08	52.10	52.16	52.18	52.18	52.140	0.10
	4	52.20	52.10	52.12	52.12	52.20	52.148	0.10
13.00	1	52.14	52.12	52.18	52.12	52.20	52.152	0.08
	2	52.12	52.20	52.12	52.18	52.22	52.168	0.10
	3	52.16	52.12	52.18	52.12	52.18	52.152	0.06
	4	52.10	52.06	52.18	52.18	52.22	52.148	0.16
14.00	1	52.14	52.12	52.14	52.24	52.24	52.176	0.12
	2	52.06	52.10	51.98	52.14	52.16	52.088	0.18
	3	52.08	52.12	52.16	52.10	52.20	52.132	0.12
	4	52.16	52.12	52.18	52.16	52.18	52.160	0.06
15.00	1	52.12	52.12	52.12	52.14	52.08	52.116	0.06
	2	52.18	52.10	52.18	52.14	52.16	52.152	0.08
	3	52.12	52.24	52.22	52.12	52.26	52.192	0.14
	4	52.06	52.10	52.12	52.18	52.12	52.116	0.12
16.00	1	52.16	52.20	52.16	52.24	52.12	52.176	0.12
	2	52.14	52.18	52.20	52.16	52.06	52.148	0.14
	3	52.28	52.22	52.18	52.22	52.12	52.204	0.16
	4	52.24	52.18	52.24	52.18	52.18	52.204	0.06
17.00	1	52.14	52.22	52.14	52.16	52.22	52.176	0.08
	2	52.14	52.12	52.08	52.22	52.20	52.152	0.14
	3	52.12	52.00	52.12	52.08	52.16	52.096	0.16
	4	52.06	52.10	52.12	52.14	52.18	52.120	0.12
18.00	1	52.12	52.12	52.10	52.12	52.12	52.116	0.02
	2	52.08	52.10	52.14	52.16	52.18	52.132	0.10
	3	52.08	52.10	52.16	52.18	52.18	52.140	0.10
	4	52.20	52.10	52.12	52.12	52.20	52.148	0.10
19.00	1	52.16	52.12	52.10	52.16	52.18	52.144	0.08
	2	52.12	52.12	52.14	52.24	52.20	52.164	0.12
	3	52.30	52.12	52.16	52.18	52.16	52.184	0.18
	4	52.22	52.12	52.18	52.16	52.14	52.164	0.10
20.00	1	52.14	52.10	52.18	52.12	52.20	52.148	0.10
	2	52.22	52.20	52.12	52.08	52.22	52.168	0.14
	3	52.16	52.22	52.18	52.12	52.18	52.172	0.10
	4	52.10	52.06	52.18	52.18	52.22	52.148	0.16
21.00	1	52.16	52.12	52.10	52.16	52.18	52.144	0.08
	2	52.00	52.12	52.14	52.20	52.20	52.132	0.20
	3	52.30	52.12	52.16	52.18	52.16	52.184	0.18
	4	52.22	52.12	52.18	52.16	52.14	52.164	0.10
22.00	1	52.12	52.12	52.12	52.14	52.08	52.116	0.06
	2	52.18	52.10	52.18	52.14	52.16	52.152	0.08
	3	52.12	52.24	52.22	52.12	52.26	52.192	0.14
	4	52.06	52.10	52.12	52.18	52.12	52.116	0.12

Table 24.01: Hourly Data from 4 machines for Flange thickness 52.15 +/- 0.25 mm

Machine No.	1	2	3	4
R bar (mm)	0.0840	0.1227	0.1293	0.1133
X Double bar (mm)	52.147	52.146	52.163	52.146
UCL for range chart (mm)	0.1772	0.2588	0.2729	0.2391
UCL for mean chart (mm)	52.195	52.217	52.238	52.212
LCL for mean chart (mm)	52.098	52.075	52.088	52.081
Sigma (σ)	0.0361	0.0527	0.0556	0.0487
Process capability Index Cp	2.308	1.580	1.499	1.710
Process capability Index Cpk	2.227	1.556	1.418	1.686

Table 24.03: Machine wise results for Flange thickness 52.15 +/- 0.25 mm

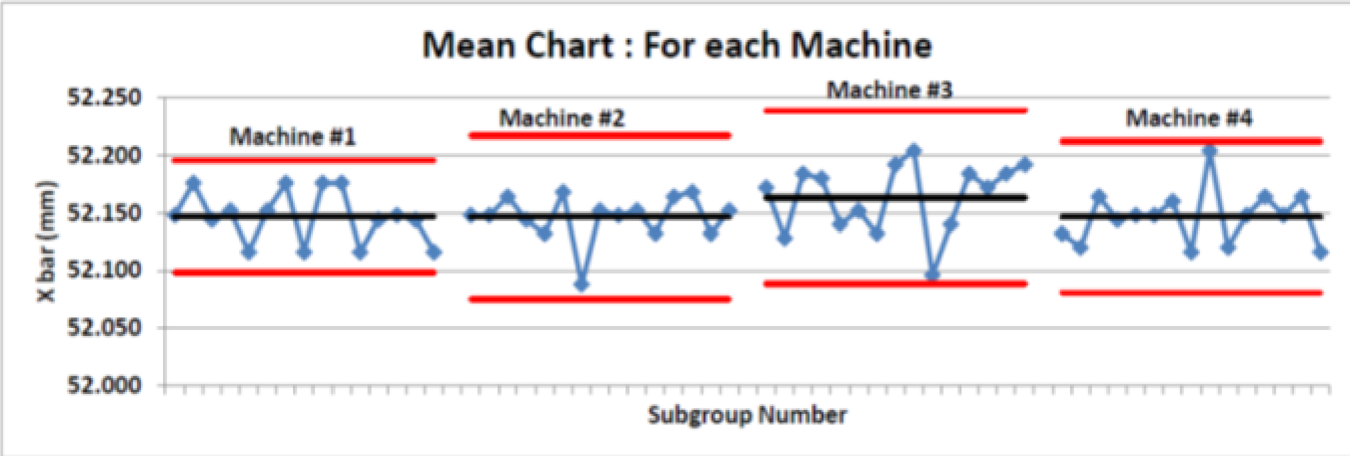

Figure 24.03: Combined Mean Chart for each Machine

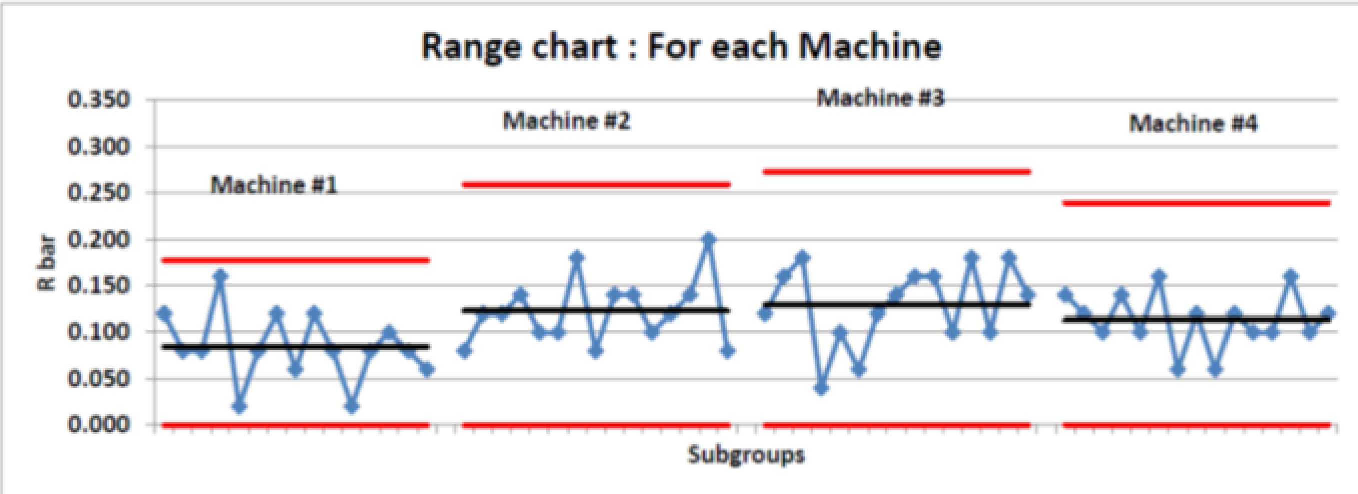

Figure 24.04: Combined Range Chart for each Machine

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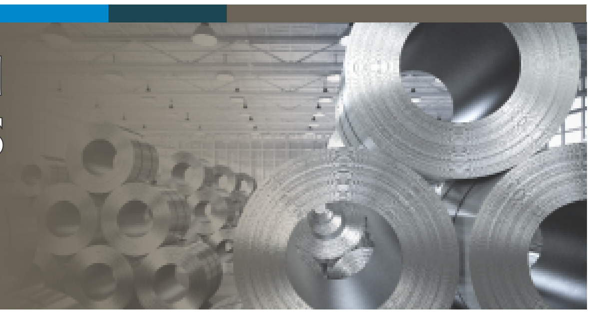

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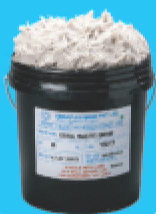
Hot top Rings, Transition Plates, Inserts, Spouts, Washers

Launder, Basin, Ladle, Filter Holder

Ceral Mastic



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Integrated modelling of deformations and stresses in the die casting and heat treatment process chain

Jesper Thorborg, Jörg Klinkhammer and Heinz-Jürgen Gaspers, Aachen

MAGMA Gießereitechnologie GmbH, Aachen, Germany

.... Continued from December 2019 Issue

12 Pre-shaping the die to compensate for as-cast distortion

In addition to the different correction methods, which are applied to the part as shown in the previous sections, it is of coursevital to use a reasonable shrinkage factor in the design of the die and when possible pre-shape the die to reduce the as-cast distortion. The procedure for using simulation to pre-shape the die is illustrated in Figure 14.

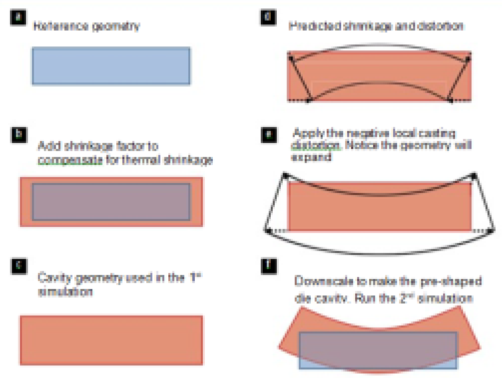

Figure 14: Procedure for pre-shaping the die. Reference geometry (a), enlarged geometry to compensate for thermal shrinkage (b), cavity geometry for the rst calculation (c), predicted shrinkage and distortion (d), applied local negative casting distortion (e) and pre-shaped die cavity for second simulation (f).

To generate the red pre-shaped die cavity in Figure 14f the procedure is as follows:

The blue reference geometry Figure 14a is scaled up according to the shrinkage factor of the aluminum alloy, red rectangle in Figure 14b. This is a standard procedure to account for the thermal contraction of the casting during solid cation and cooling.

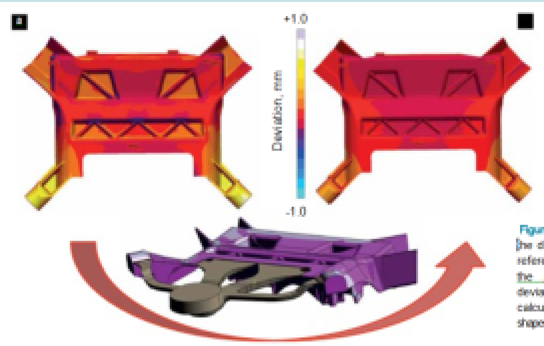

Figure 15: Pre-shaping of the die. Deviation from the reference geometry after the rst simulation (a) and deviation after the second calculation where the pre-shaped cavity is used (b).

- The first simulation is based on the up-scaled die cavity in shown red in Figure 14c and the results are indicated by the black line geometry in Figure 14d. The four small arrows in the corners of the two geometries in Figure 14d indicate the predicted distortion.
- This result is multiplied by a negative scale below -1.0 and applied as a correction factor to the die cavity shown by the black line geometry in Figure 14e. The correction is indicated by the four arrows. The negatively deformed geometry is scaled down and used as the new cavity shape, red shape in Figure 14f.
- The applied negative correction expands the geometry and a last down scale is applied to predict the new pre-shaped cavity.
- A second simulation is used to check to which extend the pre-compensation corrects the original distortion.

Depending on the complexity of the geometry, it can be difficult to correct distortion in all regions of the part even if the steps above are repeated several times. However, compared to making changes to the real die, the above simulation approach is a very attractive way of evaluating how far as cast distortions can be reduced by pre shaping the die.

To illustrate the die pre-shaping procedure, a space frame connection node is used as an example. The node considered connection is shown in Figure 15. The deviation from the reference geometry after casting using the original cavity dimensions is in the range of 0.9-1.0 mm as shown in Figure 15a. The negative of the casting distortion shown in Figure 15a was used to correct the dimensions of the die. In Figure 15c the grey colored part illustrates the dimensions for the original cavity geometry, and the purple color indicates the modified cavity geometry using the predicted distortion shown in Figure 15a. After compensating the distortion by pre-shaping the die, the level of deviation from the desired geometry is reduced to be less than 0.3 mm as shown in Figure 15b.

13 Analyzing the ejection process

The location and number of ejection pins governs the stability of the ejection process of the cast part from the die. It is important to design a layout which distributes the required ejection forces in a way that the part does not stick to the die or deform the part. Simulation can be used to evaluate different layouts, and by that add pins where ejection forces reach a critical level and remove pins where they have little or no effect. Design constraints from e. g. the cooling system and die inserts can, of course, be considered when the locations are evaluated.

The ejection process is evaluated for a space frame connection node, where the initial layout of 12 ejector pins was simulated and the results were used to check the force level on the different ejector pins. Based on the results, four pins were removed from the layout and results from a new simulation were compared to the original layout Figure 16.

The ejection process for the initial layout is visualized in Figure 17. The three snapshots show the deformed part during ejection with a magnification factor of 5.

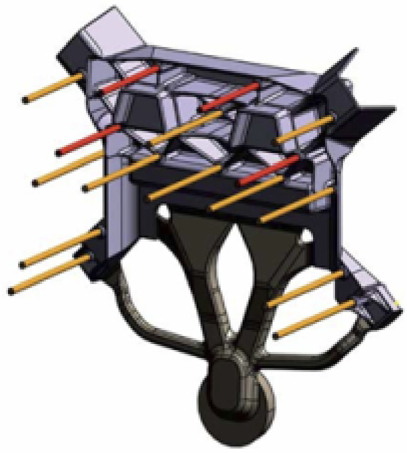

Figure 16: Layout of the ejector pins, where the red pins are not active in the second simulation.

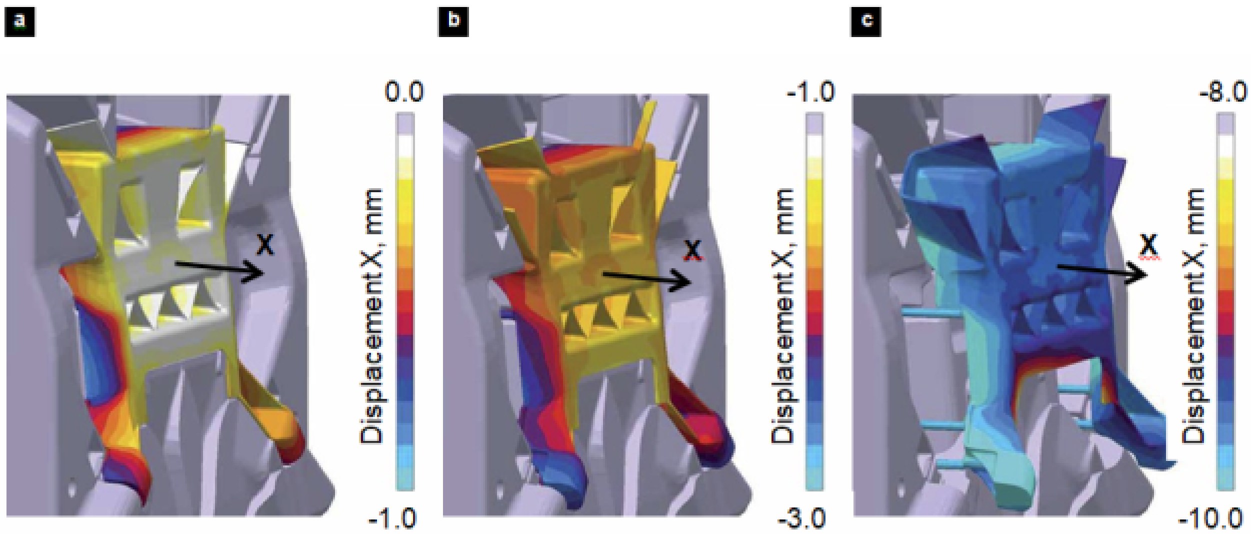

Figure 17: Deformation of the part during the ejection process (5x magnification). The snapshots show from the left: The beginning of ejection (a), the time where the forces are highest (b) and the end of the ejection (c).

The ejector pins are controlled by a time dependent displacement input and the pins will force the part out of the die as function of time. The interface between the part and the ejector die is described by a Coulomb friction model, which governs the reaction forces depending on the shrinkage induced clamping.

The contact pressures between the ejector pins and the part are evaluated for the initial case where all pins are active. It is possible to visualize the pressure directly on the part, which is shown as an example in Figure 18 after approximately 1 second. Only half of the part is shown due to the symmetry.

Two points are identified as having a relatively low contact pressure and hence used as candidates for being removed (four points in total only two are shown due to symmetry). They are highlighted as R1 and R2 in Figure 18. The two points in the lower left corner of the part also show relatively low contact pressures. However, they are kept in the layout due to their location, since removing them could increase the risk of the part tilting and sticking during the real ejection process.

The two identified pins, R1 and R2, were removed and the second reduced layout was simulated. To evaluate the consequences of removing the two pins, the contact pressure in three of the remaining points were compared to the results from the first calculation.

The results are compared in Figure 19, where the normalized contact pressure is shown as a function of time at the three points. The full lines show the results for the first case with all pins active and the dashed lines show the results for the second case where four pins are removed from the layout. The contact pressure is generally increased in all three points, but a further evaluation of the general stress state in the part during ejection did not show critical stress levels and no significant permanent deformation was detected due to the change in the number of pins. The reduced number of ejection pins in the second case therefore

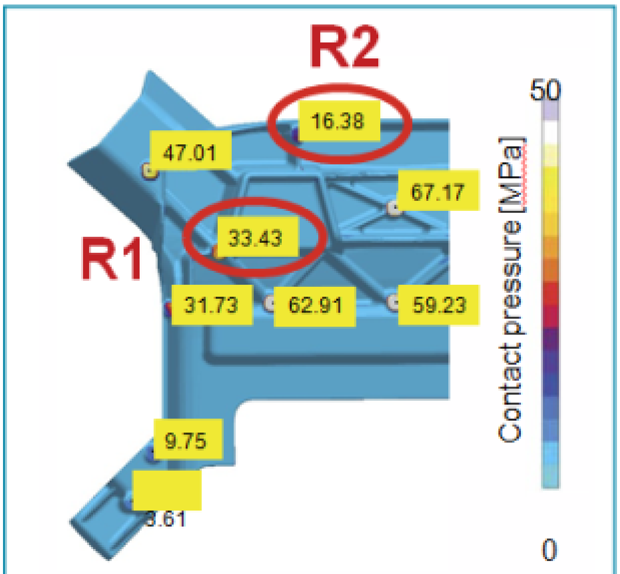

Figure 18: Contact pressure in the interface zones betweenthe part and the ejector pins. The contact pressure is shown after approximately 1 second. Due to symmetry, only half of the part is shown.

14 Design of virtual experiments for support frame optimization

The thermal example is another space frame connecting node treatment support frame was evaluated by performing a virtual DOE varying the number and location of the applied front supporting beams in the frame; see Figure 20. The presented results are from the research project "ProGRes", [6, 7]. The objective was to minimize the deformation of the part by changing the layout of the support frame, while keeping the solution treatment parameters fixed at 2 hours and 485 °C.

The results of the DOE simulations are shown in Figure 21. For the frame in Figure 21a, 3.2 mm is predicted in the direction of gravity in the left front area of the part.

Using an additional support in the front left corner of the frame, the deformation is significantly reduced, Figure 21b.

The next variation is done by taking away one of the front support beams. This variation has only a minor effect on the deformation of the part Figure 21c. Moving the front left support beam further left and to the back of the geometry seems to lead to the best result of the performed variations, with the lowest displacements in the gravity direction, Figure 21d.

The results from the DOE made it possible to select a design of the support frame that could significantly reduce the distortion of the part. The changes in design were automatically generated and simulated.

The sensitivity to oven temperature and treatment time was evaluated in a separate DOE and the overview of the results is shown in Figure 22. On the x-axis the holding time of the solution treatment is plotted, and the y-axis shows the maximum difference of deformation in the part compared to the reference geometry. The green coloured dots show the simulation results for the solution treatment temperature of 485 °C, red dots show the results for 535 °C and the blue ones show the results for 465 °C.

The diagram clarified that for the same holding time (e.g. 2 hours) the solution treatment with the highest temperature shows the highest deformations of the treated part. At the same time the diagram illustrates the clear tendency towards higher deformations for longer treatment times for the same temperature levels. The tendencies of different coloured dots in the diagram show that the values on the y-axis increase analogous to the x-values.

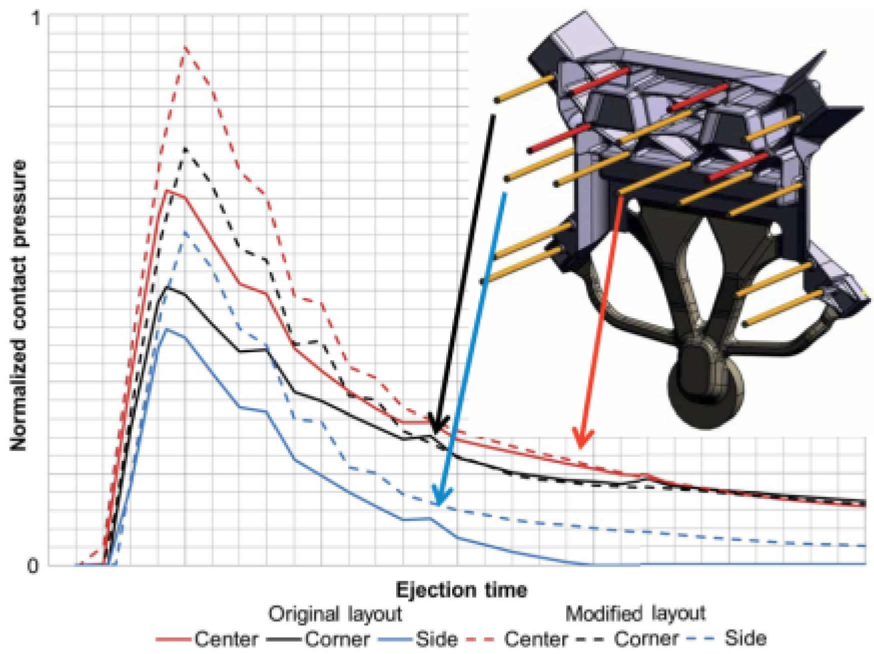

Figure 19: Contact pressure as a function of time in the 3 indicated ejector pins. Full lines are the original layout and the dashed lines are the reduced layout without the red pins.

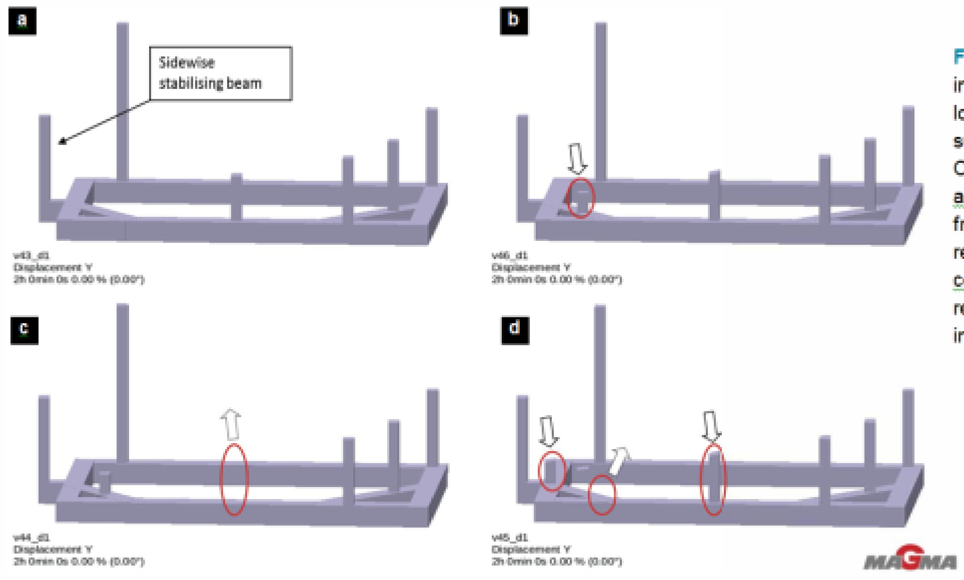

Figure 20: Variations in the number and location of the front support frame beams. Original layout (a), adding a beam in the front left corner (b), removing a front center beam (c) and repositioning the pins in the front (d).

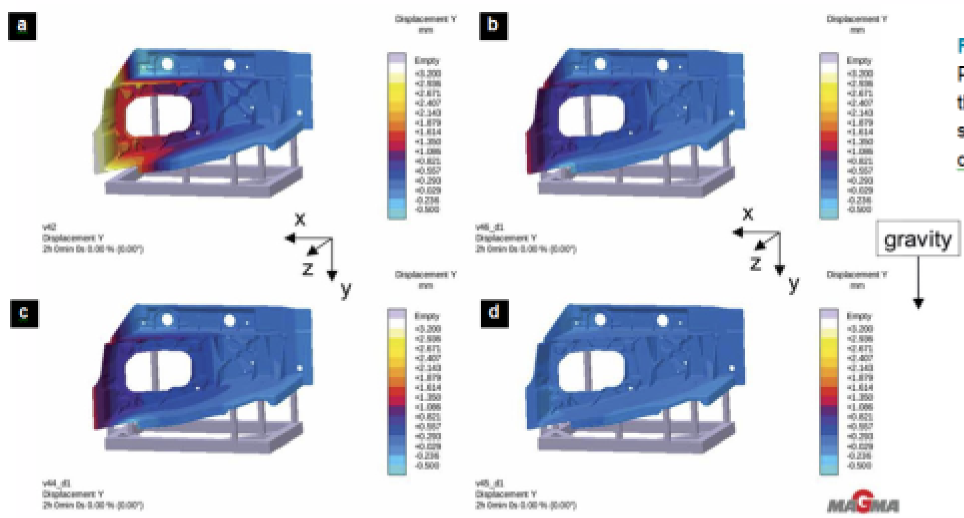

Figure 21: Predicted distortion in the part for different support frame configurations.

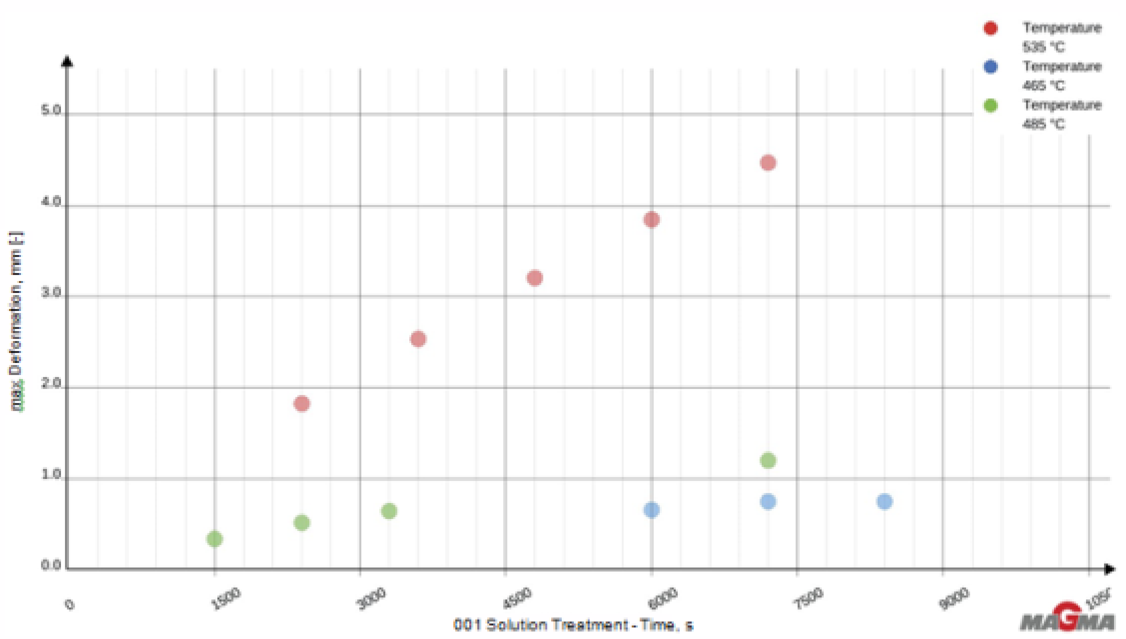

Figure 22: Results of a virtual Design of Experiments. Maximum part deformation during heat treatment for different solution treatment temperatures and times.

15 Summary

Integrated modeling of casting and heat treatment processes provides a powerful tool for an upfront assessment of critical material conditions and the influence of changing process parameters. Using virtual DOE in the design phase and during process optimization provides a unique possibility to control distortion and meet tight tolerance requirements. Detailed simulations of specification process steps and the integration of results from the different manufacturing processes provide a fundamental understanding of the complex conditions in the casting and heat treatment processes. As this virtual approach can be applied already during casting and process design, it offers the opportunity to avoid most of the currently performed experiments and measurements from production, where expensive changes to the process or design delay the production significantly. It also helps to reduce costly and time consuming tool changes or modi cations of heat treatment supports. The system matic implementation of virtual Design of Experiments into the product and process development chain is a powerful methodology to establish robust process conditions before the first casting is made.

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Appendix 1: Thermo-mechanical constitutive model.

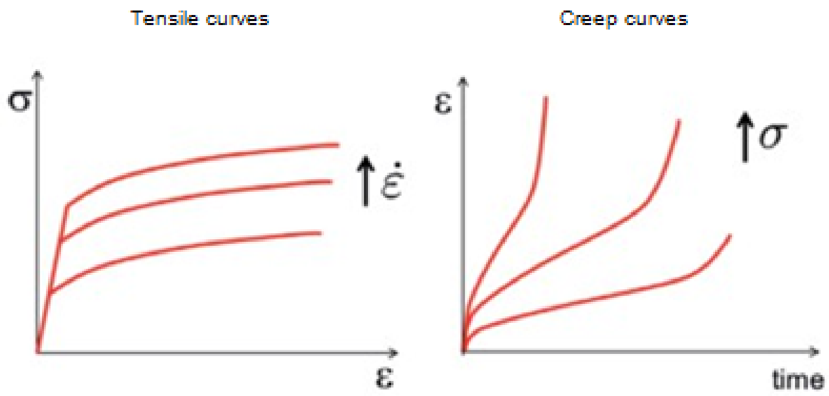
Thermo-mechanical constitutive model

Thermo-mechanical modeling of the casting and heat treatment process has to consider the complex behaviour of the material response and the interaction between the casting material and the surrounding dies and support frames. One of the main concerns is to model the response of the material at different temperature levels, on different time scales and sometimes with different strain rates, which is governed by different deformation mechanisms. A united creep formulation is used as the fundamental constitutive law, [4]. The model is based on Norton's power law and includes by that, strain rate sensitivity and the possibility to describe creep at elevated temperatures:

$$\dot{\varepsilon}^{in} = A\, exp\left(\frac{-Q}{RT}\right)\left(\frac{\sigma}{\sigma_{ref}}\right)^{m} \quad \text{and} \quad \sigma_{ref} = \sigma_{0,ref}\left(1 + \frac{E\,\varepsilon^{in}}{n\,\sigma_{0,ref}}\right)^{n}.$$

The two properties A and m describe the strain rate sensitivity. The Arrhenius expression scales the response according to the temperature dependency and the model is therefore applicable over a wide temperature range. The temperature dependency is governed by the activation energy, Q. The reference stress σ_{ref} describes the isotropic strain hardening by a classical power law, where the inelastic strain, ε^{in}, is used to capture the effect of hardening when e.g. dislocations are piling up and annealing when the temperature is elevated, accounting for diffusion processes.

The hardening response is governed by Two temperature dependent properties, the initial reference stress $\sigma_{0,ref}$ and the hardening parameter n. The response of the creep equation and the hardening law can be illustrated by classical Creep curves and the strain rate Dependent tensile curves see the two Gures to the right.



Calibration of the thermo-mechanical properties is based on a large range of tensile tests and creep tests at different temperature levels. The tensile tests are typically performed at different strain rates at intermediate and high temperatures to get information about the strain rate sensitivity. Creep tests are performed at high temperatures to get information for the heat treatment process and for slow cooling casting processes, where stress relaxation is important.

Continued to Next Page...

Coffee Talk

COFFEE TALK 8th JANUARY 2020

Speaker : Ashish Mane

Subject : Courage

Appendix 2: Casting process overview. Summary of the different process steps during casting and the typical observed behaviour of the mechanical fields.

Casting Process Overview

Thermo-mechanical modeling of the casting and heat treatment process has to consider the complex behaviour of the material response and the interaction between the casting material and the surrounding dies and support frames. One of the main concerns is to model the response of the material at different temperature levels, on different time scales and sometimes with different strain rates, which is

Solidification and cooling inside the die

- Stresses build up during cooling due to constraints from the die
- Plastic strain is generated due to the constrained deformation

! Check temperature level to evaluate when the die should be opened

! Evaluate the level of the shrinkage factor applied to the die

Ejection process

- Stresses are relaxed
- Distortion builds up during die open and ejection

! Check if the force levels on the pins are similar or if some pins experience less or higher forces than others

! Compare the contact pressure when the number of pins and the location of the pins are changed

! Enlarge the design space for the cooling system

Cooling/Quenching outside the die

- Thermal contraction governs thermal size and shape of the part
- Stresses build up for high thermal gradients

! Evaluate how the die open temperature affects thermal size due to different levels of free thermal contraction

! Check how different cooling histories affect the level of the stresses

Trimming step

- Stresses are redistributed when the gating and other materials are removed from part

! Check if high stresses build up when load carrying material is removed

Appendix 3: Heat treatment overview. Summary of the different heat treatment steps and how the thermal load influences the mechanical behaviour.

Heat treatment overview

Thermo-mechanical modeling of the casting and heat treatment process has to consider the complex behaviour of the material response and the interaction between the casting material and the surrounding dies and support frames. One of the main concerns is to model the response of the material at different temperature levels, on different time scales and sometimes with different strain rates, which is

Positioning on support frame and mapping results

- ! Designing an appropriate support frame for the heat treatment Process, e.g. to compensate for casting distortions during solution treatment
- ! Positioning of the deformed part
- ! Optimize the support frame to meet the requirements of the reference/ target geometry

Solution treatment

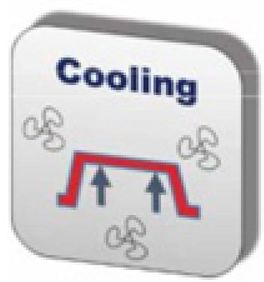
- Initial conditions from the casting process, i.e. stresses and deformations
- Relaxation of the stresses during heating and solution treatment
- ! Deformations due to gravity and the influence of the location of the support frame
- ! Check if stresses are relaxed at the end of the process step and the deformation level is acceptable

Quenching

- Stresses build up during quenching, depending on the cooling rates and thermal gradients
- Thermal contraction reduce the size of the part
- ! Check if the cooling conditions promote unwanted stresses due to the thermal gradients

Artificial ageing

- Moderate stress relaxation due to the elevated temperature level
- ! The influence of the temperature level on final stress level could be checked



Cooling

- Thermal contraction reduces the size of the part
- ! The final shape of the part can be evaluated and compared to the reference geometry and measurements if available

We are proud of you. Hearty Congratulations

Award received from Mr. Santosh Gangwar, Union Minister Labour and Employment

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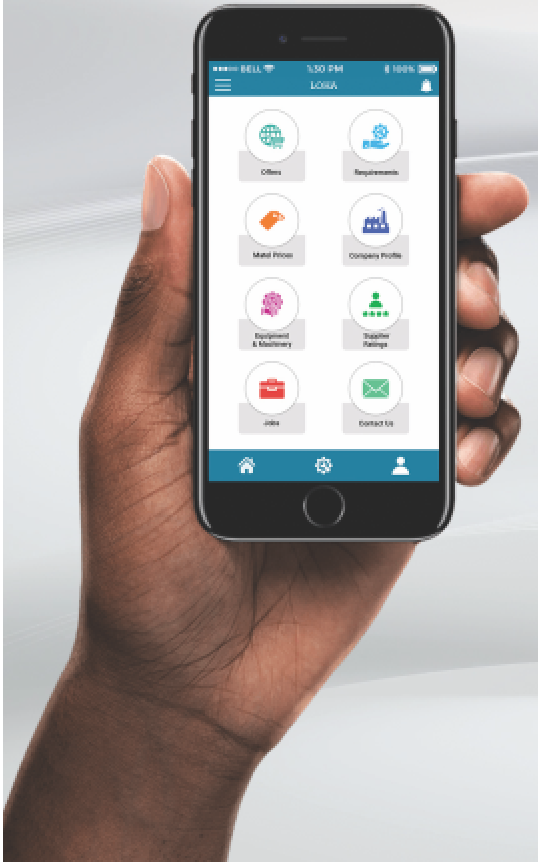

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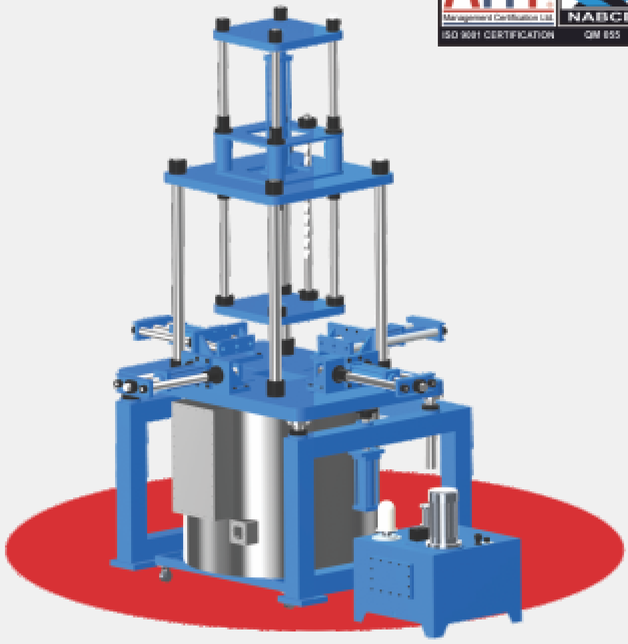

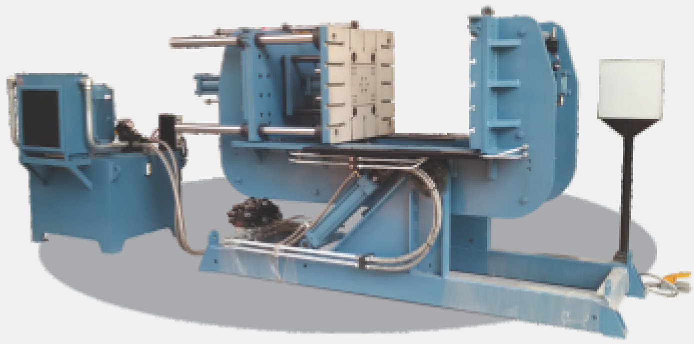

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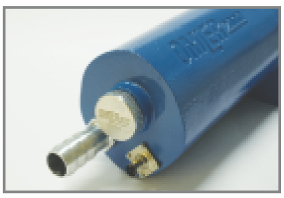

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