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Dimensional Data Analysis of Ferrous Lost Foam Castings

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ABSTRACT

This study reassesses tolerances in traditional lost foam ferrous castings. The tolerances found differ from the 1990s industry standards, tolerances of 0.005 in. (0.127 mm) for the first in. (25.4 mm) and 0.003 in. (0.0762 mm) per in. Analyzing 1655 measurements from seven companies, all customers of one lost foam foundry in the early 2000s. A consistent linear tolerance of 0.0041 in. per in. (0.0041 mm per mm) across all dimensions was found. This contradicts previous assumptions about differing linear tolerances for the first inch of castings versus the remainder of the dimensions. Larger parts showed better dimensional control than expected. However, data for parts over 11.8 in. (300 mm) was limited. These results serve as a valuable benchmark of lost foam tolerances in the past. These findings could potentially expand the applicability of lost foam casting in manufacturing.

Keywords: tolerances, ferrous, cast iron, lost foam, dimensional control, sand, ceramic, coating, casting

INTRODUCTION

Lost foam casting is a relatively new casting technology that was invented in the 1950s and put into production in the 1980's.[1] In the 1990s and early 2000s, industry standards suggested that this process could achieve tolerances of 0.005 in. (0.127 mm) for the first in. (25.4 mm) and 0.003 in. (0.0762 mm) per in. thereafter.[2] For smaller batches or prototypes using CNC-machined foams, even tighter tolerances of up to 0.002 in. (0.051 mm) per in. were considered possible. These standards have guided manufacturing decisions for decades, positioning lost foam casting as a competitive option among various metalcasting processes.

However, as with any manufacturing technology, advancements in materials and techniques necessitate periodic reassessment of these accepted standards. This study set out to verify or challenge the long-held tolerance expectations for lost foam casting using data collected from seven different companies over several years in the early 2000s.

By employing a high-precision coordinate measuring machine (CMM) as in Figure 1, a small study was undertaken to provide an updated and accurate picture of achievable tolerances in industrial lost foam casting applications.

When compared to other metalcasting processes, lost foam casting occupies a unique position in terms of achievable tolerances.[4] The "Steel Castings Handbook Supplement 3" by the Steel Founders Society of American (SFSA),[5] which is from the same era as this study (Table 1), uses a different methodology to calculate tolerances. This separate study considers the weight of the casting, which can be important for processes other than lost foam. It provides general tolerances for different casting processes.

According to "Supplement 3," traditional green sand casting typically offers tolerances of ±0.030 in. (0.76 mm) for a 1-in. cube, with tolerances increasing for larger dimensions. Chemically-bonded sand casting achieves slightly better tolerances at ±0.020 in. (0.51 mm) for a 1-in. cube. Shell molding provides tighter control at ±0.008 in. (0.20 mm) for the same dimension. At the high-precision end of the spectrum, investment casting can achieve tolerances of ±0.005 to ±0.010 in. (0.13 to 0.25 mm) for a 1-in. dimension. The findings of this study suggest that lost foam casting can achieve a consistent linear tolerance of 0.0041 in. per in. (0.0041 mm per mm) across all dimensions, challenging traditional assumptions about its capabilities. This places lost foam casting in a highly competitive position, offering better dimensional control than traditional sand casting methods, especially for larger parts, and approaching the precision of more expensive processes such as investment casting.

The implications of the findings could be significant for the manufacturing industry. If lost foam casting can consistently achieve tighter tolerances than previously thought, it could expand its applicability across various sectors, potentially offering a more cost-effective alternative to other high-precision casting methods for certain applications.

Table 1. General Comparison of Steel Casting Methods[6]

Casting requirements	Green sand	Chemically bonded	Shell	Investment
Surface smoothness	Fair	Good	Good	Excellent
Minimum metal section-mm (in).	6 (0.25)	5 (0.19)	4 (0.16)	2 (0.06)
Total (6σ) tolerance for a 100 mm (4in.) features – mm (in.)	3.4 (0.13)	2.5 (0.10)	1.7 (0.07)	0.8 (0.03)
Added total tolerance-mm (in.) across a parting face	3 (0.12)	4 (0.16)	2 (0.06)	No parting -
Intricacy	Fair	Good	Very good	Excellent
General Machine Finish allowances **mm (in.)	6 (0.25)	Most 5 (0.19)	2 (0.06)	Least 0.5 (0.02)
Normalized Pattern costs	100%	80%	250%	175%
Lead time (pattern)	18 weeks	12 weeks	20 weeks	22 weeks
Lead time (existing pattern)	6 weeks	6 weeks	6 weeks	8 weeks
* Values are presented for comparison only and should not be used directly as design tolerances on drawings, or for pattern procurement.				

By reassessing and potentially updating the tolerance standards for lost foam casting, this study aims to provide valuable insights for manufacturers, engineers, and researchers. The goal is to contribute to the ongoing evolution of metalcasting technologies, ensuring that industry practices are aligned with the most current capabilities of this versatile clean manufacturing process.

METHOD

PARTICIPANTS

Data was collected from seven different companies from multiple sectors. These customers were selected to represent a cross-section of the industry, varying in size (from 1 in. cubed to 12 in. by 8 in by 28 in. (25.4 mm cubed to 305 mm by 203 mm by 711 mm), weight (1 pound to 450 pounds (0.5 kg to 204 kg) and specialization, to offer a complete picture of the lost foam processes capabilities.

MATERIALS

The lost foam casting dimensions studied were produced using either expanded polystyrene (EPS) or ClearCast foam. These beads were then blown into parts. The foams were allowed to age at least 10 days before they were gated to allow for dimensional stability. The foams were then bottom gated in the usual Lost Foam method using an EPS gating system. Subsequently they were then coated in a ceramic coating - Borden P2325. Finally, after drying they were placed in olivine sand and cast in either gray or ductile iron.

A Mitutoyo Bright M-710 Coordinate Measuring Machine (CMM) was used to take precise measurements of cast parts. The CMM was calibrated to measure accuracy up to 0.0001 in. (0.00254 mm). The parts measured varied in size, complexity, foam material, and grades of ductile and gray iron representing a range of typical ferrous lost foam castings at that time.

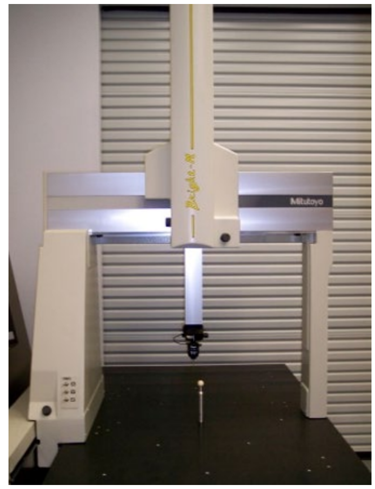


Figure 1. A photograph of the coordinate measuring machine (CMM) used in this study.

PROCEDURE

Data collection occurred over several years in the early 2000s with the same Mitutoyo Bright M-710 CMM (see Figure 1). Prior to measurement, all parts underwent a standardized temperature stabilization process. Parts were kept in a temperature-controlled room for a minimum of 12 hours to ensure dimensional stability.

The measurement environment was maintained at 72°F ± 1°F (22.2°C ± 0.56°C) with a relative humidity below 40%.

A total of 41 dimensions were measured across various parts, resulting in 1655 total measurements. For each dimension, the nominal (intended) measurement was recorded along with the actual measurement. A graph was created with the difference (Y-axis) over nominal (X-axis).

DATA ANALYSIS

The absolute difference between nominal and actual measurements was calculated to determine the achieved tolerance for each measurement. Data cleaning involved removing measurements of parts that had obvious casting defects such as cold shuts or partially formed parts.

The data had two kinds of cast iron (ductile and gray) and two kinds of Styrofoam™ along with a large size and weight distribution. This added a large amount of variability to this small study.

Linear regression analysis (Figure 2) was performed to quantify the relationship between nominal dimensions and achieved tolerances.

A linear regression model with the intercept forced through zero was chosen. This decision was based on several factors:[3]

- Theoretical Justification: It is logically impossible to have negative in this context, suggesting that the true relationship between nominal dimensions and tolerances must pass through the origin.
- Improved Model Fit: Comparison of models with and without a forced zero intercept showed that the zero-intercept model provided a substantially better fit to the data. The coefficient of determination (R^2) improved from 0.54 with a free intercept to 0.71 with a forced zero intercept.
- Practical Interpretation: A zero intercept in this context implies that a part with zero nominal dimension would have zero-dimensional error.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.84
R Square	0.71
Adjusted R Square	0.71
Standard Error	40.70
Observations	1655.00

ANOVA

	df	SS	MS	F	Significance F
Regression	1.0	6587605.3	6587605.3	3977.7	0.0
Residual	1654.0	2739233.9	1656.1		
Total	1655.0	9326839.2			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	172.7	2.7	63.1	0.0	167.3	178.0	167.3	178.0

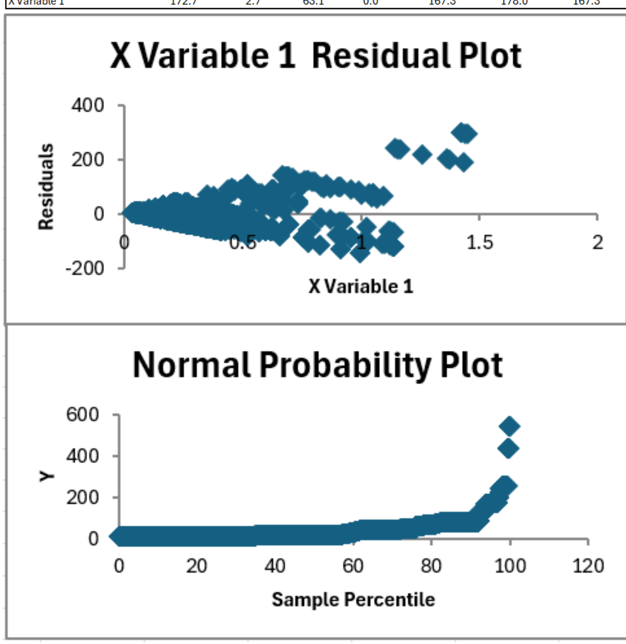


Figure 2. Regression analysis with the intercept at zero.

Analysis involved plotting the absolute difference between nominal and actual measurements against the nominal dimension. A linear difference per in. (mm) was observed across all measurements, with no significant difference found between the tolerances in the first in. (mm) and subsequent in. of the castings.

Linear regression analysis was performed to quantify the relationship between nominal dimensions and achieved tolerances. The slope of this regression line represents the linear tolerance per in. achieved in the lost foam casting process. The coefficient of determination (R^2) was calculated to assess the strength of this linear relationship. Examination of the residuals indicated that they were approximately normally distributed (with a slight left skewness), supporting the validity of the linear regression model (Figure 3),

In Figure 3, the slope of this regression line represents the linear tolerance per in. achieved in the lost foam casting process for this study. It is important to note that while this model provides a good fit for the range of dimensions studied (from approximately 1/4 in. to the maximum CMM capacity), extrapolation to dimensions outside this range should be done with caution.

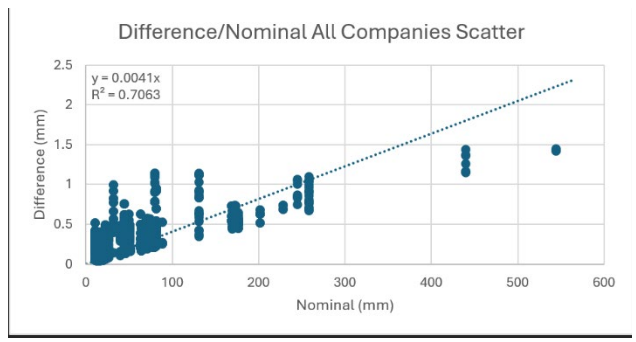
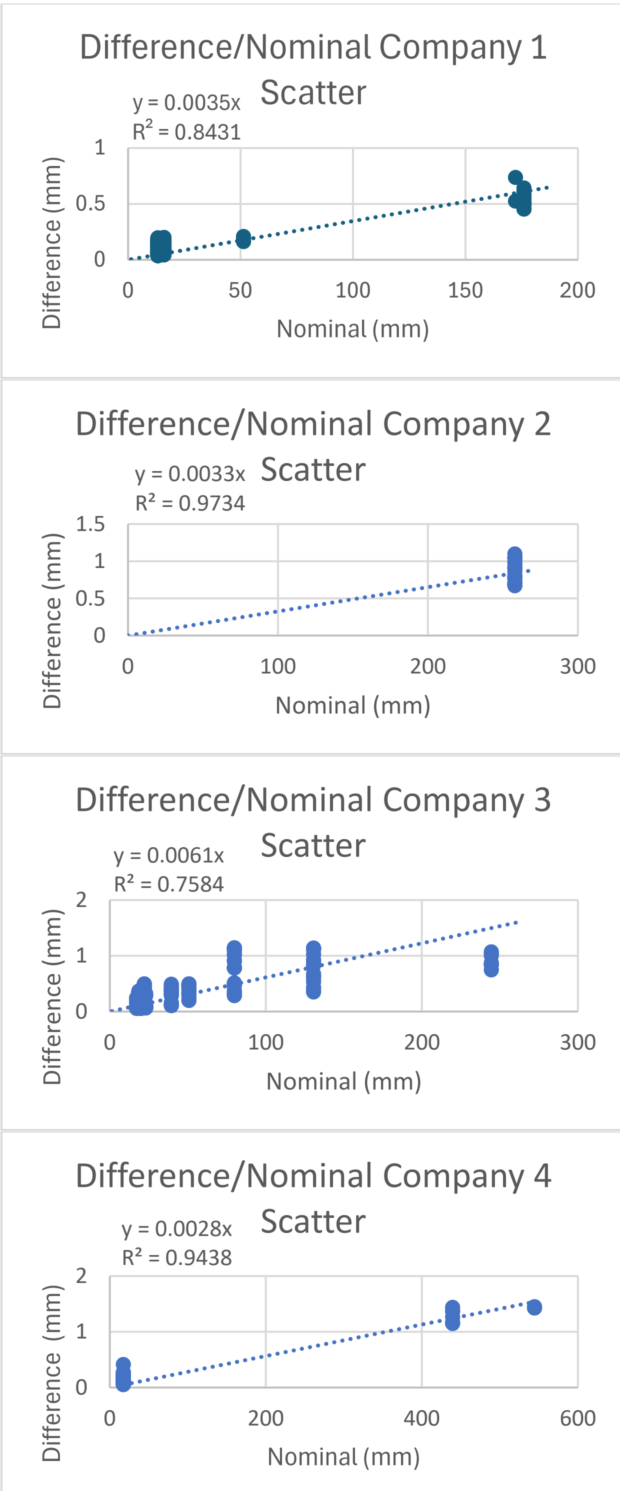


Figure 3: Difference/Nominal scatter plot showing tolerances as dimensions get larger prepared by author.

At the extreme maximum of the CMM's capacity, which coincided with the maximum size of the foam machine and production process, additional variables and dimensional uncertainty were introduced. Interestingly, better dimensional control than expected was observed for larger parts. However, for measurements over 300mm, the dataset was limited, precluding definitive conclusions for this size range.

This analysis approach allowed for a comprehensive understanding of the tolerance trends across all dimensions of the cast parts allowing for a full picture, while also illuminating the limitations of the study at extreme measurement ranges. The unexpected, better performance at larger sizes, despite increased variables,

provides valuable insights into the capabilities and potential of the lost foam casting process.
The regression analysis suggested that with more data points, especially for larger dimensions, there may be an increased chance to correct for dimensional uncertainty. This finding points to potential areas for future research and process improvement.



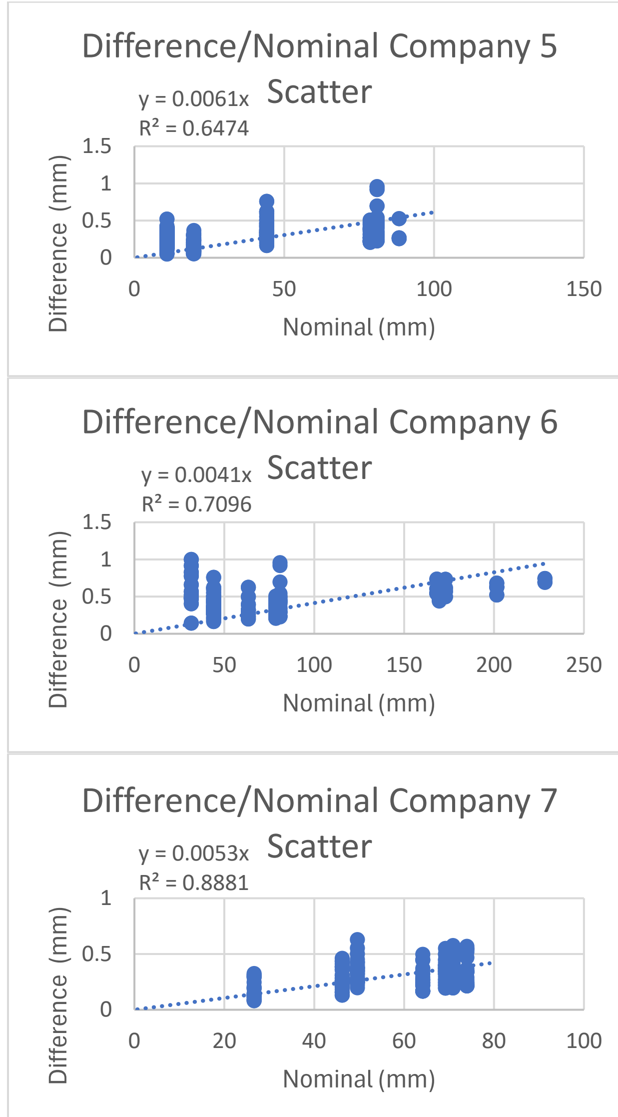


Figure 4. Individual company regression analysis plots showing their individual tolerances and R—squared value.

Figure 4 presents individual company regression analysis plots, highlighting the tolerances and R-squared values for seven different companies involved in the lost foam casting process. These plots offer valuable insights into the performance variations across different manufacturers and sizes. This illuminates the importance of bringing together the individual companies (Figure 3) to create a wholistic picture of the ferrous lost foam process.

CONCLUSIONS

While this small study focuses on data from the early 2000s, it is worth noting that the lost foam casting process continues to evolve. Advancements, such as improved ceramic coatings and the use of synthetic ceramic sand, promise even better dimensional control through a more uniform coating application and enhanced gas escape.

Although the specific impacts of these recent developments are beyond the scope of this study, they underscore the ongoing potential for improvement in the field.

This small study analyzed data from several cast parts from different companies in the early 2000s, cast at one foundry, demonstrated significant improvements in lost foam casting tolerances compared to 1990s standards. An analysis of 1655 measurements revealed a consistent linear tolerance of 0.0041 in. per in. (0.0041 mm per mm), challenging previous assumptions about the process, particularly regarding the first inch (25 mm) of castings.

These findings serve as a valuable historical benchmark, highlighting the advancements in lost foam casting over time. It is important to note that current capabilities are likely even more precise, benefiting from subsequent technological improvements such as ceramic sand and advanced coatings.

By providing this historical perspective on achievable tolerances, this study contributes to our understanding of lost foam casting's evolution and its continuing potential in modern manufacturing processes.

FUTURE RESEARCH

While this study provides comprehensive data on a wide range of part sizes, it is acknowledged there are limitations in data for exceptionally large parts (over 300mm). This presents an opportunity for future research to further refine the linear tolerance understanding of lost foam casting capabilities across all size ranges. Future research should focus on quantifying advancements made since the early 2000s, particularly for large parts (over 300mm), and exploring the impact of recent innovations such as the impact of ceramic sands and newer coatings. A much larger study is needed over multiple foundries and processes to either prove or disprove the tolerances that this analysis calculated.

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