

SFSA Supplement 3

DIMENSIONAL CAPABILITIES OF STEEL CASTINGS

1. Introduction

Dimensional tolerances are selected by the designer or purchaser to make sure that the part can perform its function reliably and fit into its designed location. Assigning dimensions to a part requires identifying the desired feature size. Tolerances communicate how much variation from the desired size can be tolerated. Overly stringent tolerances are costly and do not add value. They require added work to meet tolerances that may be beyond the process capability. Inadequate tolerances are a problem because parts may be able to meet the tolerance but fail to either fit or function in accordance with the design.

To assign dimensions and tolerances to a part that is produced as a casting involves consideration of function and fit of the finished part, allowances for machining operations involved in producing the finished part, and production requirements such as draft and taper. Allowances for castings and the major tolerance considerations in the production of parts as steel castings are presented below. Along with this information a set of tolerance grades is introduced to facilitate communication on tolerances.

2. Allowances

The shapes of cast steel components reflect not only the functional requirements of the component, but also manufacturability requirements dictated by the casting process. Castings shapes must incorporate the proper use of draft allowances for successful mold making and machining allowances for surfaces requiring more precision and better surface finishes than can be achieved in the as-cast conditions. Draft and machine finish allowance guidelines and practices are presented to assist in the specification of draft and machining allowances for castings.

Similarly, size or pattern allowances must be incorporated into the production of patterns and coreboxes from which steel castings are made. These pattern allowances (sometimes call shrink rules) must also be correctly applied to ensure that final castings can meet customer dimensional tolerance requirements without extra pattern dimension adjustment cycles. Other castability guidelines that influence the recommended geometry of steel castings are discussed in “Steel Casting Design”.¹

2.1 Draft (Taper) Allowances

Draft should be designated on the casting drawing in consultation with the casting producer—typically in a drawing note. The draft angle selected should be no less than can be tolerated in the design. Figure 2.1 illustrates the use of draft on a typical pattern and corebox.

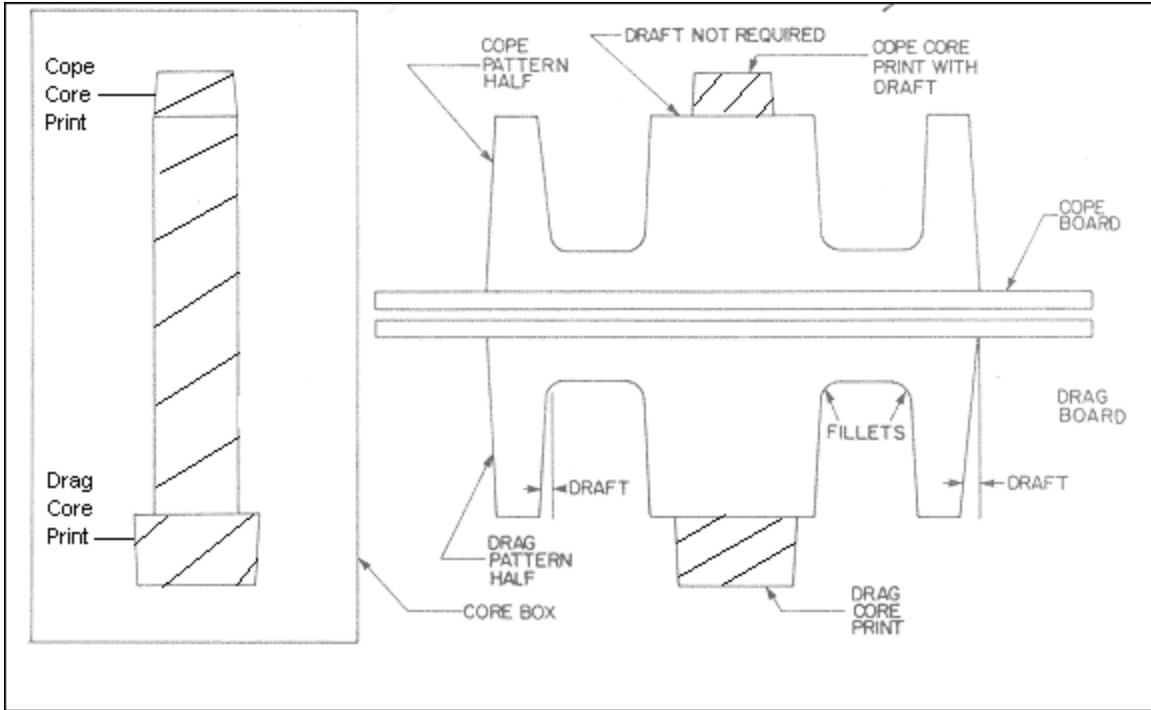


Figure 2.1 - Schematic illustration of a full split pattern and core box to produce a wheel-type casting. Note that draft is required on the vertical surfaces to allow the pattern to be drawn away from the mold. The core that will be made in the core box will form a cylindrical cavity to reduce machining.

2.1.1 Draft (Taper) Allowance Recommendations

Table 2.1 presents general draft recommendations for steel castings. To ensure moldability, it is helpful to meet or exceed these draft allowances indicated on all surfaces perpendicular to the mold parting line.

Table 2.1: Typical Draft (Taper) Allowances

Molding Process	Typical Draft (Taper) Angles	
	Most Features	Deep Pockets
Green Sand - Manual	1.5 °	2.0 °
Green Sand - Automated	1.0 °	1.5 °
No-bake & shell molding	1.0 °	1.5 °

2.1.2 Factors Affecting Recommended Draft Allowances

Machine molding will require a minimum amount of draft. Interior surfaces in green sand molds usually require more draft than exterior surfaces. Draft can be eliminated in some cases through special molding techniques, such as investment casting or through the use of cores. These situations and the specific amount of draft required should be discussed with personnel of the foundry that will produce the casting.

A specific dimensional tolerance on a drafted surface is generally referenced from the drafted surface rather than from the surface dimension before draft is applied. That is, draft is added to casting surfaces first before dimensional tolerances or geometric tolerances applied, Figure 2.2. Draft allowances can be incorporated into dimensional tolerances or geometric tolerances only upon consultation with the foundry.

The dimensional changes needed to incorporate draft can be expressed as follows:

$$DA = L \tan \theta$$

Where:

DA = Draft allowance

L = Length

θ = Draft angle

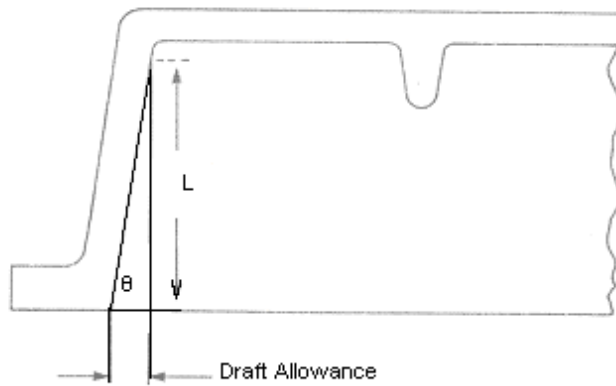


Fig 2.2 Draft angle facilitates pattern removal from the mold.

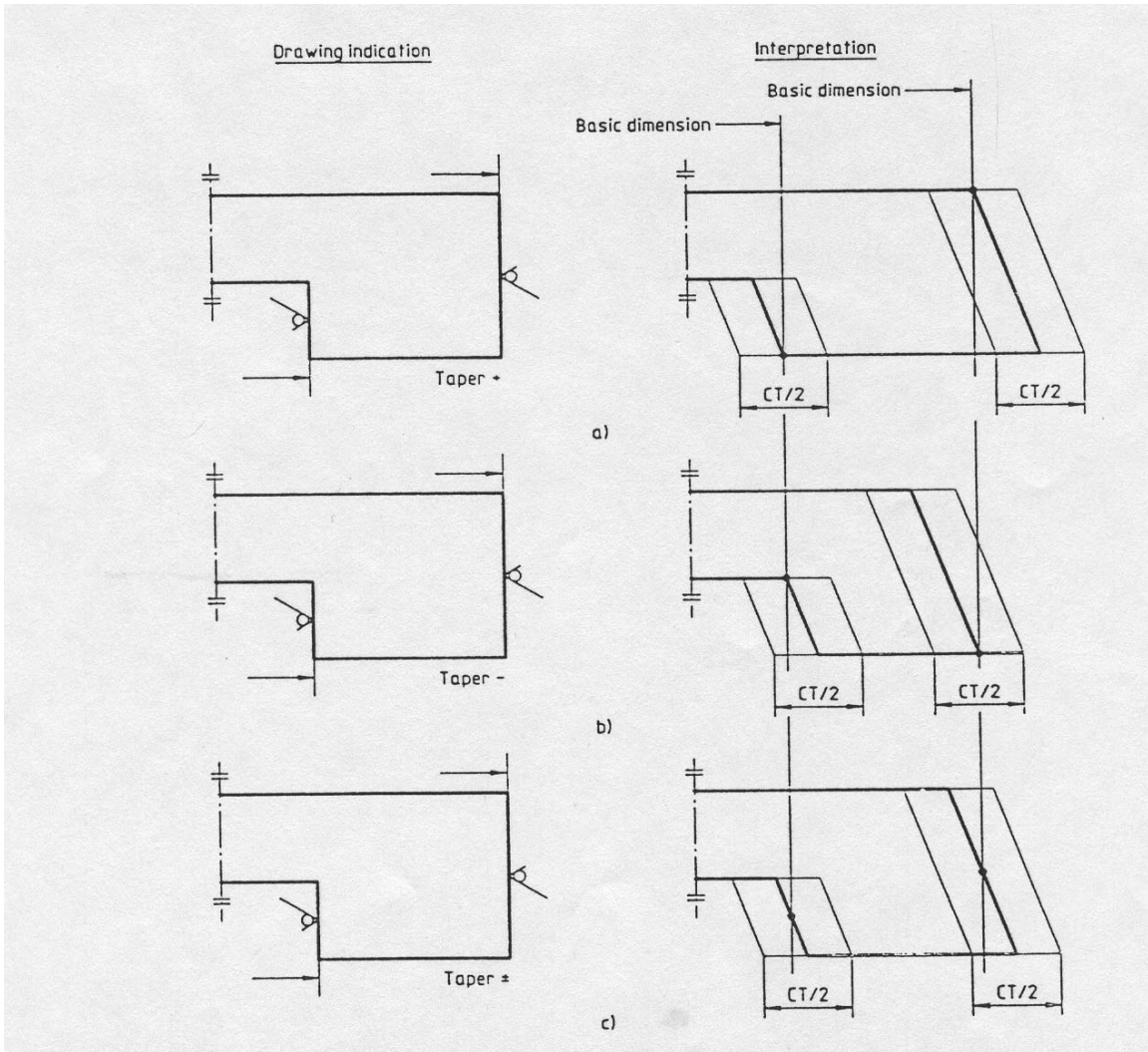


Figure 2.3 Dimensional tolerance zones on drafted (tapered) features (CT is the casting dimensional tolerance as defined in ISO- 8062)

2.2 Required Machining Allowance Guideline

Castings that are to be machined must have sufficient metal stock on all surfaces requiring machining. The necessary allowance, commonly called the required machining allowance (RMA), machine finish allowance, or machining allowance, depends upon the size and shape of the casting, the surface to be machined, the hardness of the steel, roughness of the casting surface, and the tendency to distort. The required machining allowance is superimposed upon draft and pattern allowances. Required machining allowances are typically called out in drawings with a general note.

2.2.1 Required Machining Allowance

Table 2.2 - Required machining allowances (RMA) in millimeters for steel castings based on ISO 8062.

Largest dimension mm		Required machining allowance mm Note: A minimum of 6 mm RMA required on all cope casting surfaces					
over	up to and including	Required machining allowance grade					
		E	F	G	H	J	K
-	40	0.4	0.5	0.5	0.7	1	1.4
40	63	0.4	0.5	0.7	1	1.4	2
63	100	0.7	1	1.4	2	2.8	4
100	160	1.1	1.5	2.2	3	4	6
160	250	1.4	2	2.8	4	5.5	8
250	400	1.8	2.5	3.5	5	7	10
400	630	2.2	3	4	6	9	12
630	1000	2.5	3.5	5	7	10	14
1000	1600	2.8	4	5.5	8	11	16
1600	2500	3.2	4.5	6	9	13	18
2500	4000	3.5	5	7	10	14	20
4000	6300	4	5.5	8	11	16	22
6300	10000	4.5	6	9	12	17	24
Sand casting, hand molded → use grade G – K							
Sand casting, machine molded (and shell) → use grade F – H							
Investment casting → use grade E							

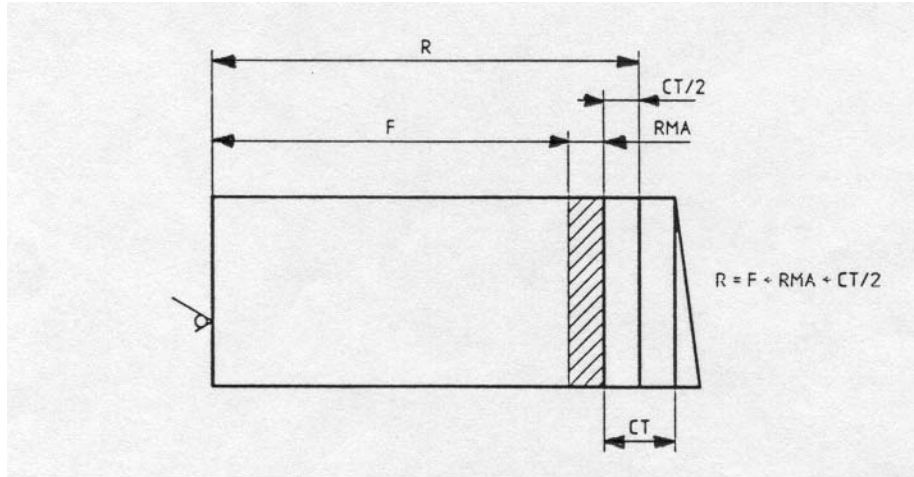
Table 2.2 - Required Machining allowance (RMA) in inches for steel castings based on ISO 8062.

Largest dimension in.		Required machining allowance mm					
		Note: A minimum of 0.25 in. RMA					
over	up to and including	Required machining allowance grade					
		E	F	G	H	J	K
-	1.6	0.016	0.020	0.020	0.028	0.040	0.055
1.6	2.5	0.016	0.020	0.028	0.040	0.055	0.080
2.5	4	0.028	0.040	0.055	0.080	0.110	0.160
6	10	0.055	0.080	0.110	0.160	0.220	0.320
10	16	0.070	0.100	0.140	0.200	0.280	0.400
16	25	0.087	0.120	0.160	0.240	0.360	0.480
25	40	0.100	0.140	0.200	0.280	0.400	0.560
40	60	0.110	0.160	0.220	0.310	0.430	0.630
60	100	0.130	0.180	0.240	0.350	0.510	0.710
100	160	0.140	0.200	0.280	0.390	0.550	0.790
160	250	0.160	0.220	0.310	0.430	0.630	0.870
250	400	0.180	0.240	0.350	0.470	0.670	0.940

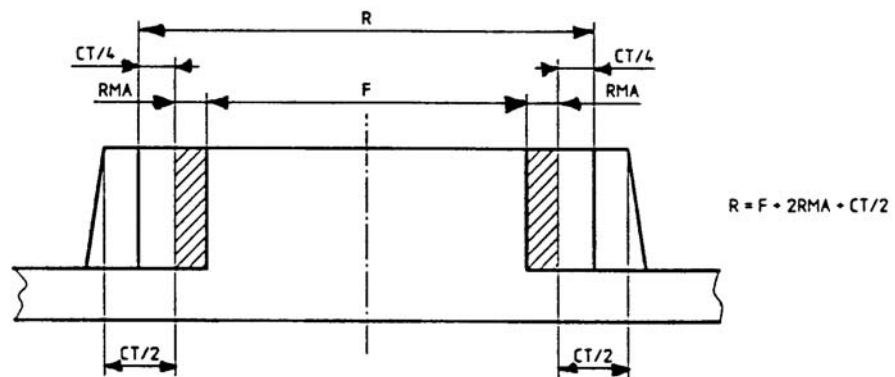
2.2.2 Factors Affecting Required Machining Allowances

The allowances expressed in Table 2.2 are conservative and should apply to short production run castings. They may be reduced for high production run castings when adequate preliminary consultation and machining trials have been carried out. Machine allowances for castings of very large size, such as greater than 15 ft (5000mm), should be determined through consultation with the foundry.

The required machining allowance, when considered along with the casting feature dimensional tolerance, should be interpreted as shown in Figure 2.4.

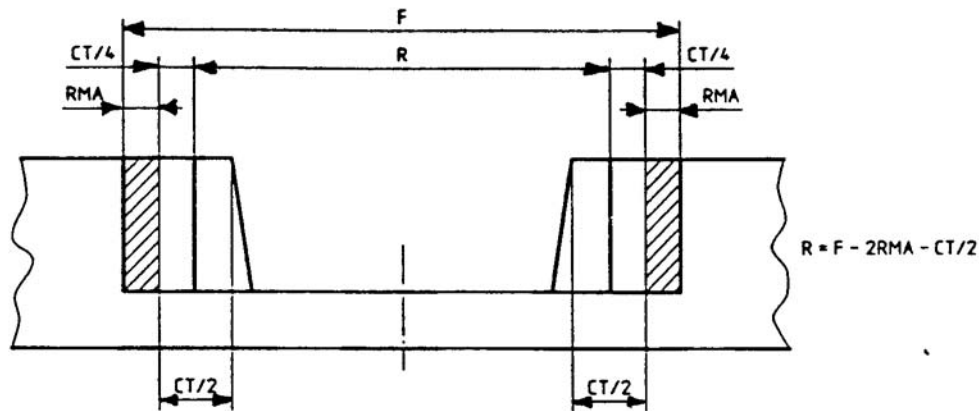


A – Machining on one side of feature

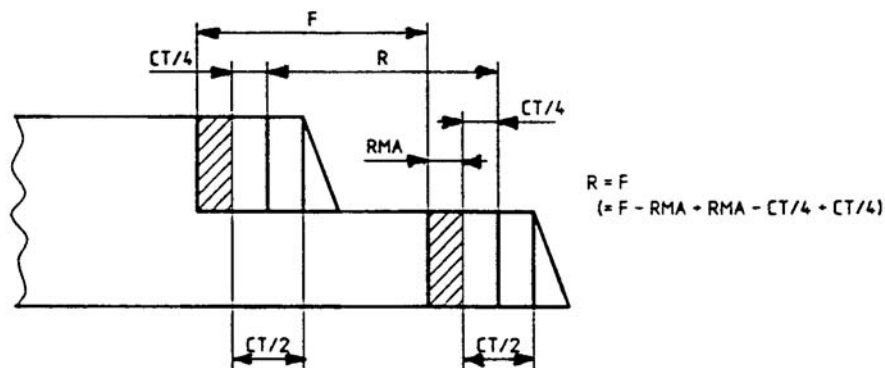


- R = Raw casting basic dimension
- F = Dimension after final machining
- RMA = Required machining allowance
- CT = Casting tolerance

B – External machining of boss



C – Internal machining



D – Machining of step dimension

Figure 2.4 Interpretation of required machining allowances along with casting feature tolerances.

The dimensional allowance to be added to the casting section for machining purposes will depend on the design of the casting. Certain faces of a casting may require larger allowances than others as a result of their position in the mold. In particular, the cope surfaces of a large casting will require larger machining allowances than the drag surfaces or side walls. For cope surfaces in particular required machining allowances for cope surfaces of less than 0.25 inches (6mm) are generally not recommended. For this reason, it is recommended that critical machined surfaces be molded in the drag whenever possible.

Sufficient excess metal should be allowed to satisfactorily accomplish the necessary machining operations. One very good rule is to allow enough "machining stock" so that the first cut remains below the cast surface on the metal by at least 1/16 in. (1.5 mm). Required machining allowances must be chosen with care. Critical surfaces that are fixtured using as-cast locators are sometimes preferred to avoid excess machine stock on critical surfaces.

3. Dimensional Tolerances

Tolerances for dimensions of as-cast features are a matter for agreement between the producer and purchaser (We do not know who the consumer is) of the castings. However, to minimize the rejection of castings for dimensional reasons, the tolerances selected should be compatible with the capability of the process selected.

Tolerances affect the cost and delivery of the castings. Most castings have only a few critical dimensions which require tight tolerances. Placing tight tolerances on dimensions which are not critical merely increases the final casting cost without benefit to the purchaser. However, where tolerances tighter than the process can normally produce are required, dimensional upgrading using one of the operations discussed later may be the least expensive method of satisfying the requirements.

The best way to make this determination is through a joint effort in a value engineering or value analysis project. Good communications of requirements on the one hand and the processes needed to meet them on the other is the key.

The International Organization for Standardization (ISO) has issued, *ISO 8062, Castings – System of Dimensional Tolerances*. This standard provides a system of tolerances and machining allowances for all castings, including steel castings. It assigns different dimensional tolerance grades based on the metal cast, the molding process used, the length of the casting feature, and the production quantity. The ISO 8062-1994 tolerancing scheme is the basis from which improved dimensional tolerances for steel castings have been developed by the SFSA. These SFSA 2000 steel casting dimensional tolerances should be used instead of the specific steel casting tolerance recommendation contained within ISO-8062-1994 for steel castings.

These new dimensional tolerance also supersede the 1997 (SFSA developed) “T grades” dimensional tolerances.

The production quantities, the casting design and the dimension type play an important role in determining the tolerances which can be met with the process because the complex contraction behavior of steel during solidification and cooling must be adequately compensated for in the construction of the pattern. The production of castings in large numbers usually provides the opportunities to make dimensional adjustments in pattern equipment or to compensate for unpredictable casting contraction behavior with one or more reverse engineering steps. These costly reverse engineering steps to adjust pattern dimensions are a function of the dimensional tolerance requirements established by the customer as well as the foundry's process variability.

The SFSA-2000 dimensional tolerances presented here are based on a statistical analysis of more than 140,000 casting features on production steel castings weighing from 6.5 to 12,000 lbs. for common steel molding processes. The dimensional capabilities from which these tolerances have been developed account for both the expected casting process variability and dimension centering errors that can be expected for typical short production series and long production series casting production, Tables 3.1-3.4.

3.1 SFSA 2000 Dimensional Tolerances for Steel Castings

Table 3.1 Casting dimensional tolerance grades from ISO 8062-1994. These grade designations also used for SFSA 2000 steel casting tolerances

Raw Casting basic dimensions, mm		Total casting tolerance mm															
Over	Up to & including	Casting tolerance grade CT															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-	10	0.09	0.13	0.18	0.26	0.36	0.52	0.74	1	2	2	2.8	4.2	-	-	-	-
10	16	0.10	0.14	0.20	0.28	0.38	0.54	0.78	1.1	1.6	2.2	3	4.4	-	-	-	-
16	25	0.11	0.15	0.22	0.3	0.42	0.58	0.82	1.2	1.7	2.4	3.2	4.6	6	8	10	12
25	40	0.12	0.17	0.24	0.32	0.46	0.64	0.9	1.3	1.8	2.6	3.6	5	7	9	11	14
40	63	0.13	0.18	0.26	0.36	0.50	0.70	1	1.4	2	2.8	4	5.6	8	10	12	16
63	100	0.14	0.20	0.28	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6	9	11	14	18
100	160	0.15	0.22	0.30	0.44	0.62	0.88	1.2	1.8	2.5	3.6	5	7	10	12	16	20
160	250	-	0.24	0.34	0.50	0.70	1	1.4	2	2.8	4	5.6	8	11	14	18	22
250	400	-	-	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6.2	9	12	16	20	25
400	630	-	-	-	0.64	0.90	1.2	1.8	2.6	3.6	5	7	10	14	18	22	28
630	1000	-	-	-	-	1	1.4	2	2.8	4	6	8	11	16	20	25	32
1000	1600	-	-	-	-	-	1.6	2.2	3.2	4.6	7	9	13	18	23	29	37
1600	2500	-	-	-	-	-	-	2.6	3.8	5.4	8	10	15	21	26	33	42
2500	4000	-	-	-	-	-	-	-	4	6.2	9	12	17	24	30	38	49
4000	6300	-	-	-	-	-	-	-	-	7	10	14	20	28	35	44	56
6300	10000	-	-	-	-	-	-	-	-	-	11	16	23	32	40	50	64

Table 3.2 Casting dimensional tolerances adapted from ISO 8062-1994, (inches), also used for SFSA 2000 steel casting tolerances

Raw Casting basic dimensions, in.		Total casting tolerance in.															
Over	Up to & including	Casting tolerance grade CT															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-	0.4	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.17	-	-	-	-
0.4	0.6	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.12	0.17	-	-	-	-
0.6	1	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.09	0.13	0.18	0.24	0.32	0.39	0.47
1	1.6	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.07	0.1	0.14	0.2	0.28	0.35	0.43	0.55
1.6	2.5	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.16	0.22	0.32	0.39	0.47	0.63
2.5	4	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.17	0.24	0.35	0.43	0.55	0.7
4	6	0.01	0.01	0.01	0.02	0.02	0.04	0.05	0.07	0.1	0.14	0.2	0.27	0.39	0.47	0.63	0.79
6	10	-	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.16	0.22	0.32	0.43	0.55	0.7	0.87
10	16	-	-	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.17	0.24	0.35	0.47	0.63	0.79	0.98
16	25	-	-	-	0.03	0.04	0.05	0.07	0.1	0.14	0.2	0.28	0.39	0.55	0.7	0.87	1.1
25	40	-	-	-	-	0.04	0.06	0.08	0.11	0.16	0.24	0.32	0.43	0.63	0.79	0.98	1.26
40	60	-	-	-	-	-	0.06	0.09	0.13	0.18	0.28	0.35	0.57	0.7	0.91	1.14	1.46
60	100	-	-	-	-	-	-	0.1	0.15	0.21	0.32	0.39	0.59	0.83	1.02	1.3	1.65
100	160	-	-	-	-	-	-	-	0.17	0.24	0.35	0.47	0.67	0.95	1.18	1.5	1.93
160	250	-	-	-	-	-	-	-	-	0.28	0.39	0.55	0.79	1.1	1.38	1.73	2.21
250	400	-	-	-	-	-	-	-	-	-	0.43	0.63	0.91	1.26	1.58	1.97	2.52

Table 3.3 SFSA 2000 for steel casting tolerance long-production series.

Conditions	Select Tolerance Grades
All sand molding process fully capable, most appropriate for large castings	CT 12-14
Appropriate for most casting types and sand molding processes	CT 10-12
Within process capabilities, but not appropriate for all casting types and sand molding processes	CT 8-10
Investment Casting	CT 5-7

Table 3.4 SFSA 2000 steel casting tolerances for short-production series steel castings

Conditions	Select Tolerance Grades
All sand molding process fully capable, most appropriate for large castings	CT 13-15
Appropriate for most casting types and sand molding processes	CT 11-13
Within process capabilities, but not appropriate for all casting types and sand molding processes	CT 9-11

Additional comments on the use of the SFSA 2000 steel casting dimensional tolerances can be found in the Appendix.

3.2 Variables Affecting Dimensional Tolerances

The aforementioned steel casting dimensional tolerance recommendations are general recommendations that can be readily used by casting customers. Comprehensive SFSA steel casting dimensional capability studies have developed more detailed information on the process and geometric factors influencing the repeatability of steel casting dimensions. Overall industry dimensional capabilities as well as the capabilities of individual foundries are fully described.

This information can be used by foundries to benchmark their dimensional capabilities, and to better quantify the effects of key variables affecting dimensional capabilities. The dimensional capability data presented here includes measurement uncertainty multiplying factors applied to the dimensional variability data from which it is based. This accounts for small non-centering errors expected during tooling validation sampling. The short production series dimensional capability prediction equations include a larger multiplying factor that accounts for non-centering errors from less rigorous sampling for tooling validation.

Casting dimensional tolerance capabilities are expressed in terms of 10%, 50%, and 90% capabilities as follows:

10% Capability = 10% of the feature capabilities were less than this limit.

50% Capability = Average capability.

90% Capability = 90% of the feature capabilities were less than this limit.

Figures 3.6-3.8 show the 10%, 50%, and 90% dimensional capabilities of 15 steel foundries using various sand molding processes compared to ISO casting tolerance (CT) grades. The foundry-to-foundry differences in dimensional capabilities reflect the broad range of casting sizes and shapes produced and the different sand molding processes used, as well as differences in process control. These key factors influencing dimensional capabilities are presented here as a guide to both the casting customer and the casting producer.

3.2.1 Production Quantity Issues

The production of castings in large numbers usually provides the opportunities to make dimensional adjustments in pattern equipment or to compensate for unpredictable casting contraction behavior with one or more reverse engineering steps. These costly reverse engineering steps to achieve dimensions may only be appropriate for high production castings. It requires the detailed dimensional characterization of many “first article” castings prior to making accurate pattern adjustments. Figure 3.1 illustrates the influence of centering on overall dimensional capabilities. The thoroughness of the casting dimensional inspection required to make adequate pattern adjustments depends on the tolerances assigned to a feature as well as to the foundries process variability.

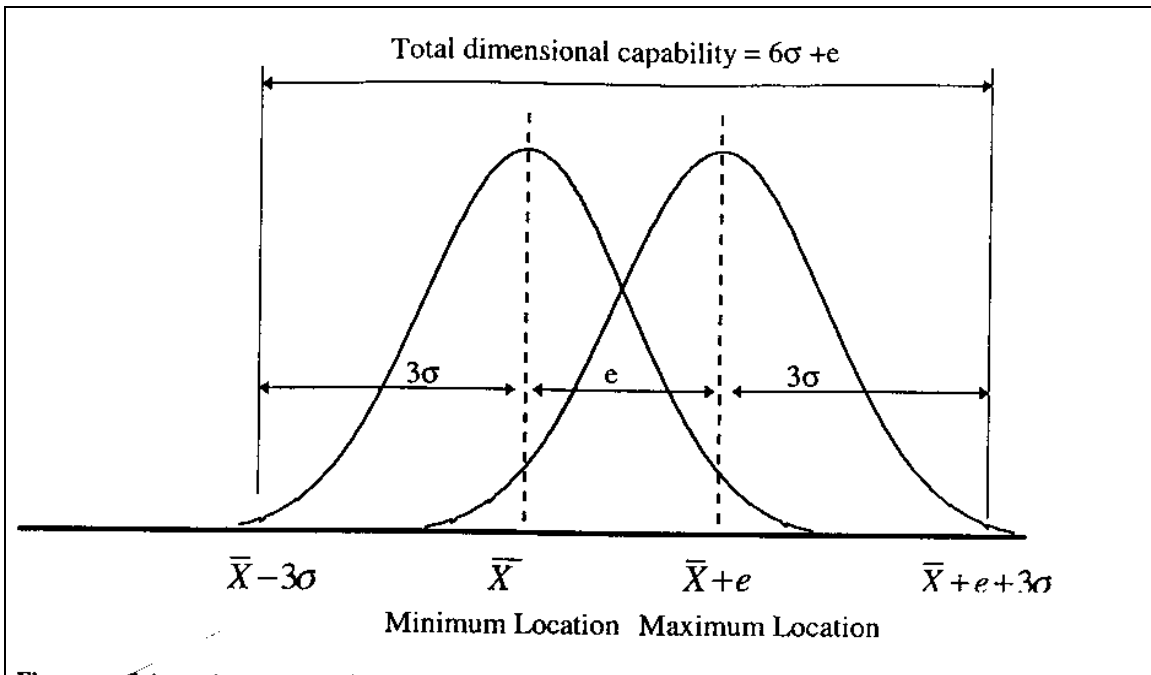


Figure 3.1 Schematic representation of total dimensional capability including sampling Uncertainty errors (e)

The number of replicate castings that must be inspected to minimize the “centering error” component of dimensional capability depends on the ratio of the foundry’s process capability compared to the casting dimensional tolerances required. This has been termed the “process capability ratio” (PCR).

$$\text{PCR} = \frac{\text{Total process variability}}{\text{Total customer tolerance}}$$

Table 3.5 indicates minimum desired lot sizes to be used for sample casting inspection based on the process capability ratio. The process capability ratio is the ratio of the foundries expected feature dimensional variability (6σ) compared to the casting feature total dimensional tolerance. If fewer sample castings than the desired number are used during pattern validation, a variability multiplying factor shown in Table 3.6 must be used to reflect additional sampling errors that are a part of the foundry’s dimensional capabilities.

Table 3.5 Statistically determined minimum number of sample castings to minimize numbers of sample castings sampling errors for various process capability ratios (for $\alpha=0.05$ and $\beta=0.05$)

Process Capability Ratio	Number of sample castings (N)
less than 0.1	1
0.1-0.2	2
0.2-0.3	2
0.3-0.4	3
0.4-0.5	5
0.5-0.6	11
> 0.6	44

Table 3.6 Dimensional variability multiplying factors for determining dimensional capabilities from dimensional variability estimates

Actual number of castings sampled (n)	Minimum desired sample size (from Table A1) (N)					
	1	2	3	5	11	44
	Dimensional Variability (6σ) Multiplying Factors					
1	1	1.32	1.32	1.32	1.32	1.32
2	1	1	1.23	1.23	1.23	1.23
3	1	1	1	1.18	1.18	1.18
5	1	1	1	1	1.14	1.14
11	1	1	1	1	1	1.09
44	1	1	1	1	1	1

These multiplying factors can be used to more correctly assess dimensional capabilities from the process variability estimates. As casting tolerances tighten, more sample castings must be inspected to minimize sampling errors. The information from Table 3.6 has been used to estimate the short production series multiplier of 1.32 and the long production series multiplier of 1.09 used as the basis for the SFSA 2000 steel casting dimensional capability's guidelines presented here.

3.2.2 Dimensional Capability Models

Major factors that influence the dimensional tolerance, which can be held, are casting geometry, the molding process, and production techniques. In general the dimensional capabilities of green sand process are similar to that of other sand molding processes for smaller castings below 50 lbs. Above 200 lbs. the no-bake process typically produces castings with tighter tolerances than green sand. The shell molding process can produce castings with the tightest tolerances of all sand molding techniques, but is limited in casting size. It is important that these statements are not taken simply at face value. It is possible for foundries to have developed great expertise and process control to produce castings to tighter tolerance standards than would be normally anticipated. When requiring tolerance requirements tighter than these indicated in the guidelines presented here, the purchaser should discuss these molding process selection issues with the foundries concerned.

Table 3.7 and Table 3.8 present dimensional capability prediction models for the various molding processes. Dimensional capabilities are expressed at 10%, 50% (average) and 90% total tolerance capabilities. For example, 90% capabilities indicate that 90% of the features measured had less variability than the total tolerance capability limit. These models have been developed from comprehensive dimensional studies of steel castings in the heat treated condition (as received by the customer) without any dimensional upgrading. The variables included in the models are the most significant factors influencing the dimensional variability of steel casting features.

Table 3.7 Dimensional capability models for steel casting (inches)

	Short Production Series	Long Production Series
Green sand (castings up to 500 lbs.)	<u>90% Capability</u> $6\sigma = 0.2050 + 0.0020 * L^{1.3} + 0.0098 * W^{0.4}$ <u>50% Capability</u> $6\sigma = 0.0842 + 0.0020 * L^{1.3} + 0.0098 * W^{0.4}$ <u>10% Capability</u> $6\sigma = -0.0363 + 0.0020 * L^{1.3} + 0.0098 * W^{0.4}$	<u>90% Capability</u> $6\sigma = 0.1710 + 0.0017 * L^{1.3} + 0.0081 * W^{0.4}$ <u>50% Capability</u> $6\sigma = 0.0701 + 0.0017 * L^{1.3} + 0.0081 * W^{0.4}$ <u>10% Capability</u> $6\sigma = -0.0303 + 0.0017 * L^{1.3} + 0.0081 * W^{0.4}$
No-Bake (castings up to 2000 lbs.)	<u>90% Capability</u> $6\sigma = 0.1410 + 0.010 * L^{0.9} + 0.0002 * W^{0.8} + 0.0483 * PL$ <u>50% Capability</u> $6\sigma = 0.0616 + 0.0087 * L^{0.9} + 0.0003 * W^{0.8} + 0.0484 * PL$ <u>10% Capability</u> $6\sigma = -0.0181 + 0.0073 * L^{0.9} + 0.0003 * W^{0.8} + 0.0485 * PL$	<u>90% Capability</u> $6\sigma = 0.1180 + 0.0084 * L^{0.9} + 0.0002 * W^{0.8} + 0.0403 * PL$ <u>50% Capability</u> $6\sigma = 0.0513 + 0.0073 * L^{0.9} + 0.0002 * W^{0.8} + 0.0403 * PL$ <u>10% Capability</u> $6\sigma = -0.0151 + 0.0061 * L^{0.9} + 0.0002 * W^{0.8} + 0.0404 * PL$
Shell (castings less than 100 lbs.)	<u>90% Capability</u> $6\sigma = 0.0805 + 0.0039 * L^{1.4} + 0.0195 * PL - 0.0018 * PL * L^{1.4}$ <u>50% Capability</u> $6\sigma = 0.0430 + 0.0038 * L^{1.4} + 0.0196 * PL - 0.0018 * PL * L^{1.4}$ <u>10% Capability</u> $6\sigma = 0.0054 + 0.0037 * L^{1.4} + 0.0198 * PL - 0.0018 * PL * L^{1.4}$	<u>90% Capability</u> $6\sigma = 0.0671 + 0.0032 * L^{1.4} + 0.162 * PL - 0.0015 * PL * L^{1.4}$ <u>50% Capability</u> $6\sigma = 0.0358 + 0.0032 * L^{1.4} + 0.164 * PL - 0.0015 * PL * L^{1.4}$ <u>10% Capability</u> $6\sigma = 0.0045 + 0.0031 * L^{1.4} + 0.165 * PL - 0.0015 * PL * L^{1.4}$
		6σ = total tolerance capability, in. PL = 1 if feature across the parting line, otherwise 0 L = feature length, in. W = casting weight, lbs.

Table 3.8 Dimensional capability models for steel castings (mm)

	Short Production Series	Long Production Series
Green sand (castings less than 230 kg)	<u>90% Capability</u> $6\sigma = 5.200 + 0.0007 * L^{1.3} + 0.340 * W^{0.4}$ <u>50% Capability</u> $6\sigma = 2.140 + 0.0007 * L^{1.3} + 0.340 * W^{0.4}$ <u>10% Capability</u> $6\sigma = -0.922 + 0.0007 * L^{1.3} + 0.340 * W^{0.4}$	<u>90% Capability</u> $6\sigma = 4.330 + 0.0006 * L^{1.3} + 0.284 * W^{0.4}$ <u>50% Capability</u> $6\sigma = 1.780 + 0.0006 * L^{1.3} + 0.284 * W^{0.4}$ <u>10% Capability</u> $6\sigma = -0.768 + 0.0006 * L^{1.3} + 0.284 * W^{0.4}$
No-Bake (castings up to 900 kg)	<u>90% Capability</u> $6\sigma = 3.590 + 0.014 * L^{0.9} + 0.010 * W^{0.8} + 1.230 * PL$ L <u>50% Capability</u> $6\sigma = 1.560 + 0.012 * L^{0.9} + 0.012 * W^{0.8} + 1.230 * PL$ L <u>10% Capability</u> $6\sigma = 0.460 + 0.010 * L^{0.9} + 0.014 * W^{0.8} + 1.230 * PL$ L	<u>90% Capability</u> $6\sigma = 2.990 + 0.018 * L^{0.9} + 0.009 * W^{0.8} + 1.020 * PL$ <u>50% Capability</u> $6\sigma = 1.300 + 0.010 * L^{0.9} + 0.010 * W^{0.8} + 1.020 * PL$ <u>10% Capability</u> $6\sigma = -0.383 + 0.008 * L^{0.9} + 0.012 * W^{0.8} + 1.030 * PL$
Shell (castings less than 50 kg)	<u>90% Capability</u> $6\sigma = 2.040 + 0.001 * L^{1.4} + 0.494 * PL - 0.0005 * PL * L^{1.4}$ <u>50% Capability</u> $6\sigma = 1.090 + 0.001 * L^{1.4} + 0.499 * PL - 0.0005 * PL * L^{1.4}$ <u>10% Capability</u> $6\sigma = 0.138 + 0.001 * L^{1.4} + 0.504 * PL - 0.0005 * PL * L^{1.4}$	<u>90% Capability</u> $6\sigma = 1.700 + 0.0009 * L^{1.4} + 0.412 * PL - 0.0004 * PL * L^{1.4}$ <u>50% Capability</u> $6\sigma = 0.909 + 0.0009 * L^{1.4} + 0.416 * PL - 0.0004 * PL * L^{1.4}$ <u>10% Capability</u> $6\sigma = 0.115 + 0.0008 * L^{1.4} + 0.420 * PL - 0.0004 * PL * L^{1.4}$
		6σ = total tolerance capability, mm PL = 1 if feature across the parting line, otherwise 0 L = feature length, mm W = casting weight, kg

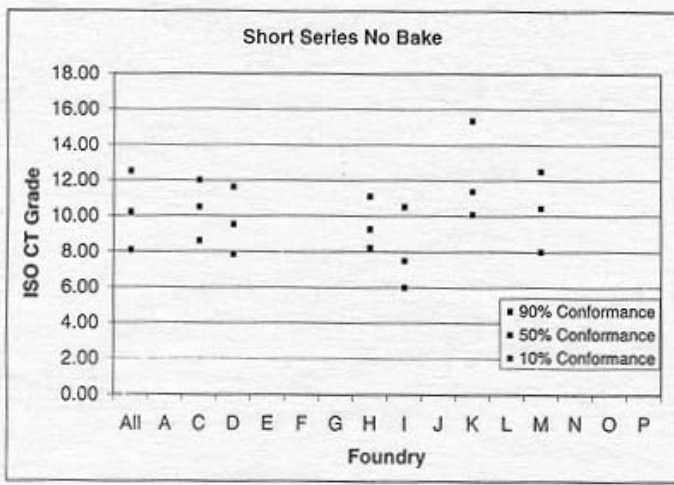
These models, from which the steel casting dimensional tolerance guidelines have been based, give a more complete picture of the expected influence of key factor influencing dimensional variability. The correlation coefficients (r^2) for these predictive equations ranged from 0.4-0.7, indicating that foundry-to-foundry variations dimensional capabilities were also significant.

The ISO 8062-based dimensional tolerance guidelines indicated the feature length alone influences the expected dimensional variability for a given molding process and production series. However, as these models indicate, casting weight and whether or not a casting feature crosses the mold parting line also influences feature dimensional variability. The use of these predictive equations for assigning tolerances for steel casting features better reflects the expected process capabilities for the steel casting industry than the simpler SFSA 2000 dimensional tolerance guidelines.

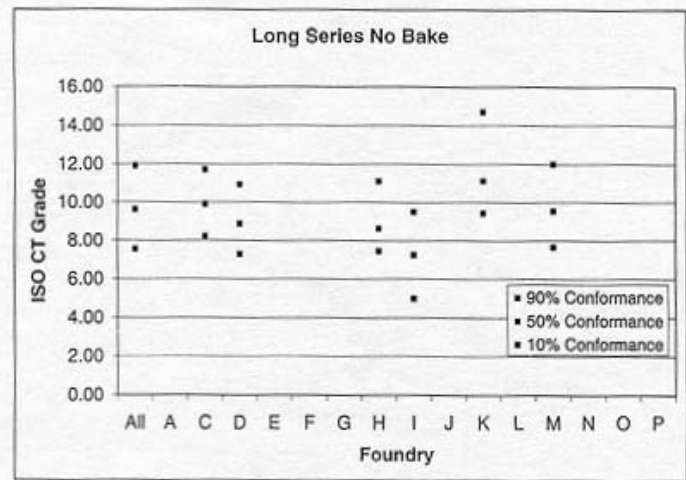
3.2.3 Molding Process

The specific molding process used to produce a steel casting can be expected to affect the dimensional capabilities. For a given size and shape sand casting shell molding can be expected to be the most dimensionally capable molding process followed by no-bake molding and green sand molding. However, the differences in dimensional capabilities for the various molding processes are less than the within foundry and foundry-to-foundry variation in dimensional capabilities for a given molding process. Therefore, although a given steel foundry may need to use the more repeatable shell molding process to hold close dimensional tolerances, another foundry may be readily able to achieve these close dimensional tolerances using green sand molding.

Figures 3.6-3.8 illustrate the dimensional capabilities of steel foundries for the individual molding processes. They are expressed as 10%, 50%, and 90% capability conformance to ISO 8062 tolerance grades for both short and long production series castings.

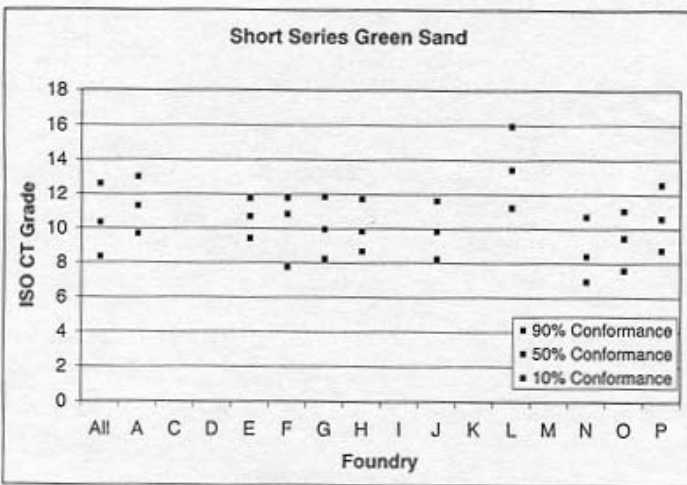


a) Short production series

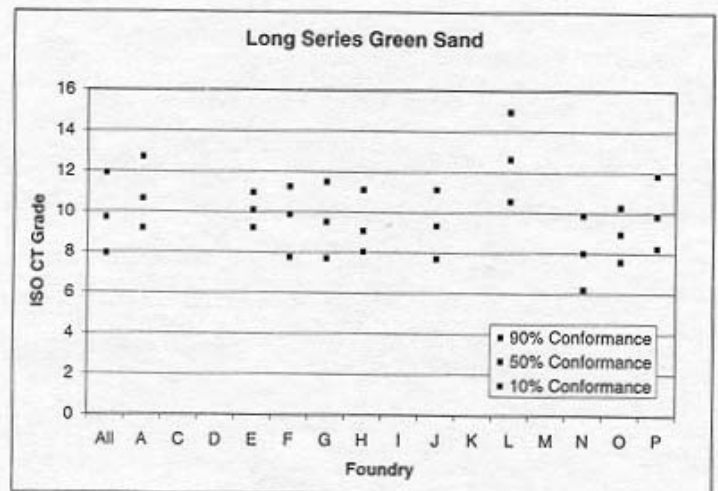


b) Long production series

Figure 3.6 Dimensional capabilities of green sand casting producers

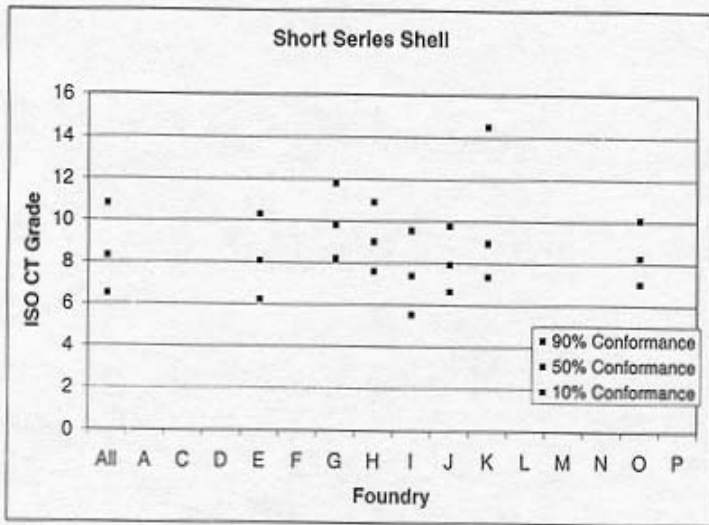


a) Short production series

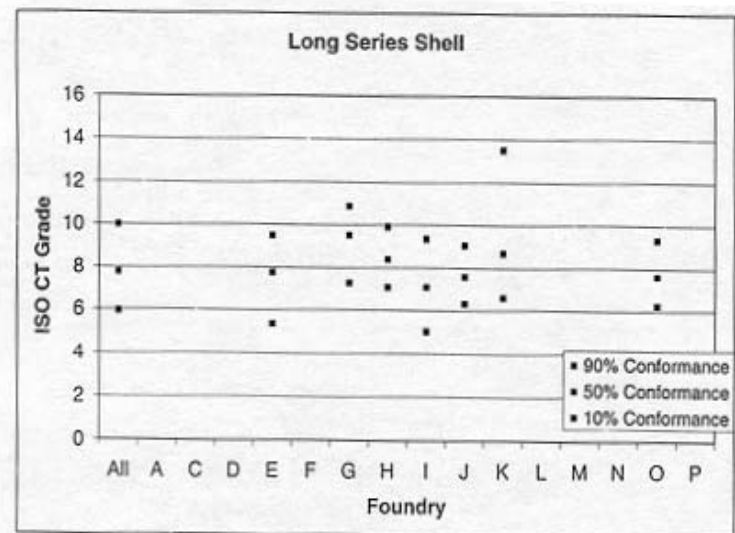


b) Long production series

Figure 3.7 Dimensional capabilities of no-bake casting producers



a) Short production series



b) Long production series

Figure 3.8 Dimensional capabilities of shell casting producer

3.2.3 Casting Geometry Features Influencing Dimensional Variability

3.2.3.1 Casting Length and Weight

It is more difficult to maintain close feature tolerances in larger castings than on small castings. Both the casting weight and the feature length influence the process capability relative to dimensional tolerances in a nonlinear fashion as shown in the predictive equations shown previously in Table 3.7 and 3.8.

As a general guideline, the expected influence of feature length and casting weight on dimensional variability can be more simply estimated, Table 3.9.

Table 3.9 Estimate of the effect of feature length and casting weight on dimensional variability

Factor	Dimensional Variability and Influence	
	(in.)	(mm.)
Feature length	0.006 in. additional 6 σ variability per inch of feature length	0.06 mm. additional 6 σ per mm of feature length
Casting Weight	0.00004 in. additional 6 σ variability per lb. of casting weight	0.002 mm. additional 6 σ variability per kg of casting weight

3.2.3.2 Mold Parting Line

Many casting features cross the mold parting line. The expected dimensional variability of these features perpendicular to the parting line includes a component of parting line variability. The expected magnitude of this parting line variability component depends on the molding process, Table 3.10.

Table 3.10 Magnitude of parting line variability

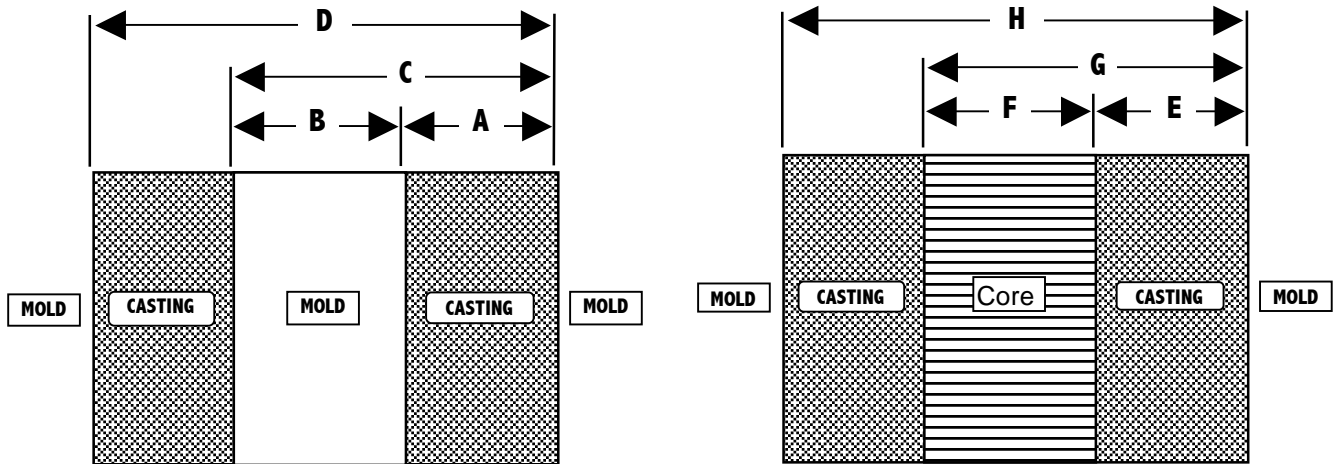
	Parting Line Dimensional Variability Component
Green Sand Molding	No significant additional variability expected
No-bake Molding	0.040 in. (1 mm) additional 6σ variability across the parting line
Shell Molding	0.008 in. (0.2 mm) additional 6σ variability across the parting line

The additional variability for no-bake casting features that cross the parting line is particularly significant. This parting line variability can be expected to vary significantly from foundry to foundry depending on the molding and tooling systems in use. The parting line component of dimensional variability for no-bake castings must be considered when selecting feature orientation for close-tolerance features.

3.2.3.3 Dimension Type

From a manufacturability standpoint various casting feature types can be described depending on whether they are controlled by the mold alone, by a core only, or by combinations of these, with and without the effect of the mold parting line, Figure 3.9. In particular, features created between the mold and a core are affected by core placement during mold closing and the relative tolerances of the core and its mating core print. These additional “degrees of freedom” created by multiple mold pieces create additional feature dimensional variables.

Similarly, close tolerance casting features exhibiting less dimensional variability can be expected when these features are created from a single component of mold or core tooling.



- A mold to mold across casting
- B mold to mold across mold
- C mold to mold across mold and casting
- D mold to mold across casting/mold/casting

- E mold to core across casting
- F core to core across core
- G mold to core across casting and core
- H mold to mold across casting/core/casting

Figure 3.9 Schematics representation of different mold relationships for dimension types

3.2.4 Foundry Process Factors Influencing Dimensional Variability

The ability of a foundry to control casting feature variability is impacted by their ability to control critical aspects of process variability. The role of individual foundry process factors on dimensional variability have been evaluated independent of casting geometry and molding process. Table 3.11 summarizes the influence of foundry process factors on dimensional variability. Major trends from this Table indicated factors that were statistically significant at confidence levels > 90%. Minor trends were also identified even though no strict statistical significance of these variables was established. Also listed are variables that appeared to have no effect on resultant casting dimensional variability independent of casting size, shape and molding process.

Table 3.11 Foundry process factor correlations influencing dimensional variability

Factor	Increase 6 σ dimensional variability
<p style="text-align: center;">Significant Correlations</p> <ul style="list-style-type: none"> ▪ Daily, instead of monthly, pin and flask alignment monitoring ▪ Very poor pattern condition instead of good pattern condition ▪ Use of separate cope and drag instead of match plate patterns ▪ Use of weighted instead of clamped molds 	<ul style="list-style-type: none"> ▪ 0.08 in. (2 mm) ▪ 0.04 in. (1 mm) ▪ 0.03 in. (0.8 mm) ▪ 0.02 in. (0.5 mm)
<p style="text-align: center;">Lesser Correlations</p> <ul style="list-style-type: none"> ▪ Largest casting dimension ▪ Cope or drag height ▪ Green sand compactibility ▪ Use of chills ▪ Use of reclaimed sand for molding 	<ul style="list-style-type: none"> ▪ 0.0004 in. (mm) additional 6σ variability per in. (mm) of largest casting dimension ▪ 0.003 in. (mm) additional 6σ variability per in. (mm) of cope or drag height ▪ 0.02 in. (0.5 mm) additional 6σ variability per unit increase in green sand compactibility number ▪ 0.02 in. (0.5 mm) additional 6σ variability for features impacted by hills ▪ 0.01 in. (0.25 mm) additional 6σ Variability for no-bake molding compared to new sand
<p style="text-align: center;">No Correlation</p> <ul style="list-style-type: none"> ▪ Alloy being cast ▪ Pour weight ▪ Mold area ▪ Casting bounding box ▪ Projected area of the casting ▪ Use of facing sand ▪ Use of mold wash 	

3.3 DIMENSIONAL CAPABILITIES – INVESTMENT CASTING

Most, if not all, investment castings are produced in long production series, where more thorough sample casting inspection and comprehensive tooling adjustments are performed prior to casting production. Therefore, only long production series capabilities are indicated in the SFSA 2000 guidelines for investment casting. The SFSA 2000 dimensional tolerance guidelines for steel castings include recommended tolerance guidelines for steel investment castings.

These recommendations better reflect the dimensional capabilities of steel investment casting than the recommendations contained in ISO 8062, or in alternative dimensional tolerance guidelines promulgated by the Investment Casting Institute.

The capability of investment casters to produce castings to the ISO 8062 casting tolerance grades is shown in Figure 3.10, expressed in terms of their 90%, 50% and 10% conformance. Considerable producer-to-producer variation is observed. This overall dimensional behavior is modeled in Table 3.12.

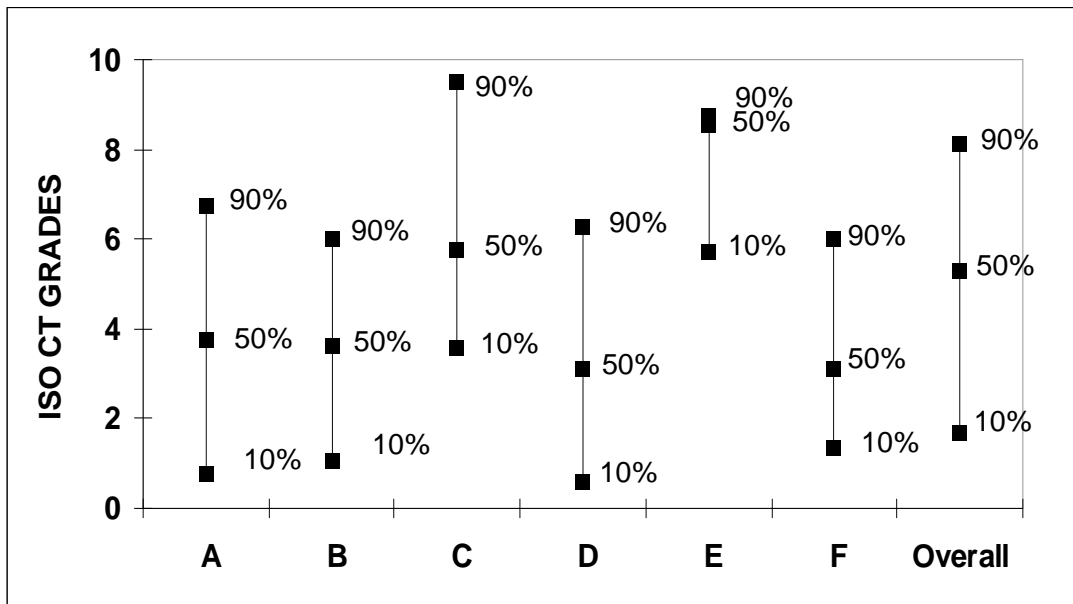


Figure 3.10 Long production series dimensional capabilities of investment castings

Table 3.12a Long Production Series Dimensional Capability – Investment Castings (in.)

90% Capability	$6\sigma = 0.285 + 0.005L + 0.0002W - 0.005PL$
50% Capability	$6\sigma = 0.083 + 0.0005L + 0.0002W - 0.005PL$
10% Capability	$6\sigma = 0.0011 + 0.005L + 0.002W - 0.005PL$

Where

6σ = total tolerance, in.

PL = 1 if feature across the parting line, otherwise 0

L = feature length, in.

W = casting weight, lbs.

Table 3.12b Long Production Series Dimensional Capabilities – Investment Castings (mm)

90% Capability	$6\sigma = 0.724 + 0.005L + 0.012W - 0.013PL$
50% Capability	$6\sigma = 0.212 + 0.005L + 0.012W - 0.013PL$
10% Capability	$6\sigma = 0.029 + 0.005L + 0.012W - 0.013PL$

Where

6σ = total tolerance, mm

PL = 1 if feature across the parting line

L = feature length, mm

W = casting weight, kg

3.4 GAGING AND DIMENSIONAL UPGRADING

The appropriate dimensional tolerances of as-cast surfaces are a matter for agreement between the producer and purchaser of the castings. However, to minimize the rejection of castings for dimensional reasons the tolerances selected should be comparable to the process capability for the particular set of operating conditions under consideration. Tolerances tighter than the process capability will necessitate that the casting be subject to special processing to upgrade the dimensional characteristics. Table 3.13 lists some of the additional operations or special manufacturing processes that may be performed to provide castings within tighter tolerance limits than can be expected from standard process capabilities.

Table 3.13 – Additional operations employed to provide tighter tolerances

<p>Pattern Upgrading</p> <ul style="list-style-type: none"> ▪ Changes in Construction, mounting and/or material ▪ Alteration of patterns after production of sample castings (i.e. movement toward long production series tolerances) <p>Molding and core making</p> <ul style="list-style-type: none"> ▪ Changes in mold making equipment or molding process ▪ Upgrading of coreboxes or adjustments in core processes <p>Finishing</p> <ul style="list-style-type: none"> ▪ Gage grinding ▪ Straighten or press to gage ▪ Coining to gage ▪ Machine locating points ▪ Rough machine to gage ▪ Target machine casting ▪ Finish machine part

3.5 Weight Tolerances

When weight considerations are important to the customer, and weight tolerances are necessary, a weight allowance is necessary to account for variations from average casting weight. Steel casting weight allowances, based on ISO 4990-1986 are summarized in Table 3.14.

Table 3.14 Casting Weight (Mass) Tolerances

Machine Molded Castings	±5% of average casting mass ¹
Hand Molded Castings	±7% of average casting mass ²
All other castings	< + 15% of calculated casting mass ²

¹ Average casting weight based on the average weight of the first five true dimension castings manufactured.

² Calculated casting weight based on the casting drawing which includes all casting allowances such as machining allowances.

4 Geometric Tolerances

Geometric tolerances are tolerances that apply to the shape features of a casting. This category of tolerances is used to control form, profile orientation and location. To completely describe the shape of a component and assign tolerances on all aspects of its shape, geometric tolerances are needed for such features as parallelism, concentricity, flatness, etc. Tables 4.1-4.4 show the geometric tolerances that can be expected for steel castings, these values are based on work involved in the development of ISO 8062-2. The reader is referred to the specification for further details regarding the use of ISO 8062-2. The nominal lengths indicated in Table 4.1-4.4 shall be the largest dimension of the considered feature or features. Table 4.5, indicates which CTG from the previous tables should be used depending on the steel casting molding process used.

Table 4.1a - Tolerances on straightness, mm

		Total geometrical tolerance mm ¹			
Over	Up to and including	Casting geometrical tolerance grade (CTG)			
		4	5	6	7
	10	0.18	0.27	0.4	0.6
10	30	0.27	0.4	0.6	0.9
30	100	0.4	0.6	0.9	1.4
100	300	0.6	0.9	1.4	2.0
300	1000	0.9	1.4	2.0	3.0
1000	3000		2.0	3.0	4.6
3000	10000		3.0	4.6	6.8

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.1b - Tolerances on straightness, in.

Total geometrical tolerance in ¹ .						
Casting geometrical tolerance grade (CTG)						
Over	Up to and including	4	5	6	7	8
	0.4	0.007	0.011	0.016	0.024	0.035
0.4	1.2	0.011	0.016	0.024	0.035	0.055
1.2	4	0.016	0.024	0.035	0.055	0.079
4	12	0.024	0.035	0.055	0.079	0.118
12	40	0.035	0.055	0.079	0.118	0.181
40	120		0.079	0.118	0.181	0.268
120	400		0.118	0.181	0.268	0.343

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.2a - Tolerances on flatness, mm

Raw casting nominal length of the feature, mm		Total geometrical tolerance mm ¹ *for reference				
Over	Up to and including	Casting geometrical tolerance grade (CTG)				
	10	4	5	6	7	8
10	30	0.27	0.4	0.6	0.9	1.4
30	100	0.4	0.6	0.9	1.4	2.0
100	300	0.6	0.9	1.4	2.0	3.0
300	1000	0.9	1.4	2.0	3.0	4.6
1000	3000	1.4	2.0	3.0	4.6	6.8
3000	10000		3.0	4.6	6.8	10
10000			4.6	6.8	10	15

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.2b - Tolerances on flatness, in.

Raw casting nominal length of the feature, in.		Total geometrical tolerance, in ¹ .				
Over	Up to and including	Casting geometrical tolerance grade (CTG)				
	0.4	4	5	6	7	8
0.4	1.2	0.011	0.016	0.024	0.035	0.055
1.2	4	0.016	0.024	0.035	0.055	0.079
4	12	0.024	0.035	0.055	0.079	0.118
12	40	0.035	0.055	0.079	0.118	0.181
40	120	0.055	0.079	0.118	0.181	0.268
120	400		0.118	0.181	0.268	0.394
			0.181			0.591

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.3a - Tolerances on circularity, perpendicularity and symmetry.

Raw casting; nominal length of the feature, mm		Total geometrical tolerance, mm ¹				
Over	Up to and including	Casting geometrical tolerance grade (CTG)				
		4	5	6	7	8
	10	0.4	0.6	0.9	1.4	2.0
10	30	0.6	0.9	1.4	2.0	3.0
30	100	0.9	1.4	2.0	3.0	4.6
100	300	1.4	2.0	3	4.6	6.8
300	1000	2.0	3.0	4.6	6.8	10
1000	3000		4.6	6.8	10	15
3000	10000		6.8	10	15	23

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.3b - Tolerances on circularity, perpendicularity and symmetry.

Raw casting; nominal length of the feature, in.		Total geometrical tolerance, in. ¹			
Over	Up to and including	Casting geometrical tolerance grade (CTG)			
		4	5	6	7
	0.4	0.16	0.024	0.055	0.079
0.4	1.2	0.024	0.035	0.079	0.118
1.2	4	0.035	0.055	0.118	0.181
4	12	0.055	0.079	0.181	0.268
12	40	0.079	0.118	0.268	0.343
40	120		0.181	0.343	0.591
120	400		0.268	0.591	0.906

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.4a - Tolerances on coaxiality

Raw casting; nominal length of the feature mm		Total geometrical tolerance mm ¹				
Over	Up to and including	Casting geometrical tolerance grade (CTG)				
		4	5	6	7	8
	10	0.6	0.9	1.4	2.0	3.0
10	30	0.9	1.4	2.0	3.0	4.6
30	100	0.4	2.0	3.0	4.6	6.8
100	300	2.0	3.0	4.6	6.8	10
300	1000	3.0	4.6	6.8	10	15
1000	3000		6.8	10	15	23
3000	10000		10	15	23	35

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.4b - Tolerances on coaxiality

Raw casting; nominal length of the feature, in.		Total geometrical tolerance in ¹ .				
Over	Up to and including	Casting geometrical tolerance grade (CTG)				
		4	5	6	7	8
	0.4	0.024	0.035	0.055	0.079	0.118
0.4	1.2	0.035	0.055	0.079	0.118	0.181
1.2	4	0.055	0.079	0.118	0.181	0.268
4	12	0.079	0.118	0.181	0.268	0.343
12	40	0.118	0.181	0.268	0.343	0.591
40	120		0.268	0.343	0.591	0.906
120	400		0.343	0.591	0.906	1.378

1) When a value is outside the table, individual tolerances shall be indicated.

Table 4.5 – Casting geometrical tolerances grades

Method	Steel
Sand cast, hand molding	6 to 8
Sand cast machine molding and shell molding	5 to 7
Investment casting	4 to 6

5. Patterns and Pattern Allowances

Patterns are manufactured so that the castings produced from the pattern are typically at the nominal (aim) dimensions of the casting drawing. The pattern and its associated coreboxes must be produced with dimensions that compensate for feature-specific contraction and distortion that takes place during casting, solidification, heat treatment and subsequent processing. This is known as the pattern allowance (or shrink rule). It can be expressed as:

$$\text{Pattern Allowance (PA)} = \frac{\text{Pattern feature size} - \text{Casting feature size}}{\text{Casting feature size}} \times 100\%$$

Foundry-to-foundry differences during processing also must be taken into account when selecting the proper pattern allowance. Castings produced from the same pattern by different foundries, or by different sand molding methods such as green sand or no-bake sand will typically not be dimensionally identical. The type of molding method can be expected to influence the effective overall casting contraction of green sand castings. Harder green sand molds produced with high pressure molding machines may require different pattern allowances that are used for similar castings using manual jolt-squeeze molding methods.

Pattern wear, as well as the shrinking and swelling of wood pattern materials due to humidity changes, can also be a source of casting dimensional variability. Dimensional variations will be greater from some pattern materials than for others. Table 5.1 contains a listing of common types of pattern materials for steel castings in order of decreasing pattern dependent dimensional variability.

Table 5.1 Degree of Variability in Dimensions for Different Pattern Materials



Loose wood pattern Pine pattern, mounted on cope and drag boards Hard wood pattern, mounted on cope and drag boards Plastic pattern, mounted on cope and drag boards Metal pattern, mounted on cope and drag boards Metal matchplate	Greatest variation	Lowest Cost
	 Least variation	 Highest Cost

Table 5.2 summarizes commonly used pattern allowances used for the production of steel castings. These overly simplified pattern allowances “shrink rules” are only a general “rule-of-thumb” that do not consider these important influences of feature type and mold type on the pattern allowance. Even though these standard, uniform pattern allowance “rules-of-thumb” are widely used, the shrinkage of individual casting features can be expected to deviate significantly from these pattern allowance nominal values.

Table 5.2 General pattern allowance values for common steel casting alloys

Alloy	Pattern Allowance	
Carbon and low alloy steel	2.08%	1/4 in/ft
High alloy steels	2.60%	5/16 in/ft

The pattern allowance value must account for more than just the shrinkage of the metal during solidification and cooling. The mold itself can be expected to undergo dimensional changes during filling, solidification and cooling. Certain casting features are restrained from contraction during solidification by the presence of the mold, others are not. Also oxide scale removed from the casting surface after cooling and subsequent heat treatment result in casting dimensional changes. The heat produced during the cooling of large castings can cause the sand mold to expand before even solidification begins. All of these factors contribute to casting dimensional changes requiring the use of not a single pattern allowance by different feature-dependent pattern allowance values to assure the conformance of all casting feature dimensions to customer dimensional specifications.

Table 5.3 gives more detailed information on pattern allowance selection for casting features not crossing the mold parting line. These pattern allowance estimates for high and low alloy steels are based on comprehensive studies of pattern allowances measured in production foundries for green sand, no-bake and shell molding.

Table 5.3 Pattern Allowance Summary (for features not crossing the mold parting line)

Condition	Average Pattern Allowance	80% Confidence Interval for Pattern Allowances
Low Alloy Steel		
Overall	1.96%	1.85 to 2.07%
Green sand molding, overall	1.60%	1.43 to 1.77%
Un-restrained features	1.56%	1.15 to 1.97%
Partially restrained features	1.74%	1.56 to 1.92%
Fully restrained features	1.61%	1.48 to 1.74%
No bake molding, overall	2.39%	2.20 to 2.58%
Un-restrained features	2.33%	1.94 to 2.74%
Partially restrained features	2.32%	2.06 to 2.59%
Fully restrained features	2.03%	1.75 to 2.30%
Shell molding, overall	2.31%	2.10 to 2.51%
Un-restrained features	2.87%	2.58 to 3.16%
Partially restrained features	2.31%	2.13 to 2.48%
Fully restrained features	1.27%	0.91 to 1.63%
High Alloy Steel		
Overall	2.92%	2.72 to 3.11%
Green sand molding, overall	4.21%	3.82 to 4.59%
Un-restrained features	3.62%	3.34 to 3.83%
Partially restrained features	--	--
Fully restrained features	5.37%	4.98 to 5.76%
No bake molding, overall	3.50%	3.08 to 3.92%
Un-restrained features	4.04%	3.46 to 4.63%
Partially restrained features*	--	--
Fully restrained features*	--	--
Shell molding, overall	2.58%	2.35 to 2.81%
Un-restrained features	2.90%	2.57 to 3.24%
Partially restrained features	2.42%	2.29 to 2.54%
Fully restrained features	1.57%	1.28 to 1.85%

6. Summary

Table 6.1 summarizes the general dimensional and cost considerations for common steel casting methods. It reflects the general capabilities common to the steel foundries. Individual foundries may have even greater dimensional capabilities and lower cost and lead time performance.

Table 6.1 General Comparison of Steel Casting Methods*

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 (6 σ) 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.				

References

- (1) Steel Casting Handbook, 5th Edition, SFSA (1980).
- (2) Karve, A., J. Chandra, and R. Voigt, "Determining Dimensional Capabilities from Short Run Sample Casting Inspection", AFS Transactions (1998).

Appendix: Guidelines for the use of SFSA 2000 Dimensional Tolerances

General

The tolerance guidelines are provided for information to be used by foundries and customers to address dimensional deviations. A customer can express the dimensional accuracy desired. A foundry can, with reference to the tolerance grade, give information on which tolerance grade or grades it normally attains with different molding methods and for different casting types.

It is recommended that the customer ask the foundry about the dimensional accuracy obtained with different molding methods and resources at its disposal. With this knowledge, the designer can decide if closer tolerances are needed for selected dimensions.

Scope

This appendix describes the tolerances, which may be achieved on steel castings produced in sand molds and for steel investment castings. Steel sand castings may be produced by molding processes such as green sand, chemically bonded sands, shell and other processes.

Purchasing information

The customer should indicate on the drawing the dimensions which are to be subject to the tolerance tables and the tolerance grades to be achieved. The required machining allowance should also be indicated when a machined part drawing is used.

Where the purchaser has supplied a drawing which indicates the machined surfaces and the machining allowance, but has not indicated the tolerance grade required for these surfaces, the foundry is free to supply the casting to their normal performance capability.

Tolerance grades

Typically, the lowest sand molding tolerance values may be expected in castings produced by the shell process. However, manufacturers may be able to achieve similar tolerances with other molding processes.

The lower number tolerance grades are more applicable to shell and no-bake molding methods. Higher number tolerance grades are applicable for many green sand-molding processes where few pattern changes and/or process adjustments can be made.

The tolerance grade specified should also reflect the extent of pattern dimensional re-engineering to center casting feature dimensions within the specified tolerances. The extent of inspection required to achieve the specified tolerance values is indicated by the selection of short production series or long production series tolerance values.

Where tighter tolerances than those found in the tables are required, these shall be agreed between the purchaser and supplier.

Inspection

The foundry will determine the compliance of the part with the purchasers' requirements.

The SFSA-2000 tolerance grades (Tables A1 to A4) are to be applied to heat treated and shot blasted production steel castings which have not been upgraded by gaging, grinding, coining, pressing or other dimensional upgrading procedures. They express the 90% conformance of foundries in terms of ISO-8062 dimensional tolerance grades.

Table A.1 Casting dimensional tolerance grades from ISO 8062-1994. These grade designations also used for SFSA 2000 steel casting tolerances

Raw Casting basic dimensions, mm		Total casting tolerance, mm															
Over	Up to & including	Casting tolerance grade CT															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
-	10	0.09	0.13	0.18	0.26	0.36	0.52	0.74	1	2	2	2.8	4.2	-	-	-	-
10	16	0.10	0.14	0.20	0.28	0.38	0.54	0.78	1.1	1.6	2.2	3	4.4	-	-	-	-
16	25	0.11	0.15	0.22	0.3	0.42	0.58	0.82	1.2	1.7	2.4	3.2	4.6	6	8	10	12
25	40	0.12	0.17	0.24	0.32	0.46	0.64	0.9	1.3	1.8	2.6	3.6	5	7	9	11	14
40	63	0.13	0.18	0.26	0.36	0.50	0.70	1	1.4	2	2.8	4	5.6	8	10	12	16
63	100	0.14	0.20	0.28	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6	9	11	14	18
100	160	0.15	0.22	0.30	0.44	0.62	0.88	1.2	1.8	2.5	3.6	5	7	10	12	16	20
160	250	-	0.24	0.34	0.50	0.70	1	1.4	2	2.8	4	5.6	8	11	14	18	22
250	400	-	-	0.40	0.56	0.78	1.1	1.6	2.2	3.2	4.4	6.2	9	12	16	20	25
400	630	-	-	-	0.64	0.90	1.2	1.8	2.6	3.6	5	7	10	14	18	22	28
630	1000	-	-	-	-	1	1.4	2	2.8	4	6	8	11	16	20	25	32
1000	1600	-	-	-	-	-	1.6	2.2	3.2	4.6	7	9	13	18	23	29	37
1600	2500	-	-	-	-	-	-	2.6	3.8	5.4	8	10	15	21	26	33	42
2500	4000	-	-	-	-	-	-	-	4	6.2	9	12	17	24	30	38	49
4000	6300	-	-	-	-	-	-	-	-	7	10	14	20	28	35	44	56
6300	10000	-	-	-	-	-	-	-	-	-	11	16	23	32	40	50	64

Table A.2 Casting dimensional tolerances adapted from ISO 8062-1994 (inches) also used for SFSA 2000 steel casting tolerances

Raw Casting basic dimensions, in.		Total casting tolerance, in.																
Over	Up to & including	Casting tolerance grade CT																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
-	0.4	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.17	-	-	-	-	
0.4	0.6	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.12	0.17	-	-	-	-	
0.6	1	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.09	0.13	0.18	0.24	0.32	0.39	0.47	
1	1.6	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.07	0.1	0.14	0.2	0.28	0.35	0.43	0.55	
1.6	2.5	0.01	0.01	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.16	0.22	0.32	0.39	0.47	0.63	
2.5	4	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.17	0.24	0.35	0.43	0.55	0.7	
4	6	0.01	0.01	0.01	0.02	0.02	0.04	0.05	0.07	0.1	0.14	0.2	0.27	0.39	0.47	0.63	0.79	
6	10	-	0.01	0.01	0.02	0.03	0.04	0.06	0.08	0.11	0.16	0.22	0.32	0.43	0.55	0.7	0.87	
10	16	-	-	0.02	0.02	0.03	0.04	0.06	0.09	0.13	0.17	0.24	0.35	0.47	0.63	0.79	0.98	
16	25	-	-	-	0.03	0.04	0.05	0.07	0.1	0.14	0.2	0.28	0.39	0.55	0.7	0.87	1.1	
25	40	-	-	-	-	0.04	0.06	0.08	0.11	0.16	0.24	0.32	0.43	0.63	0.79	0.98	1.26	
40	60	-	-	-	-	-	0.06	0.09	0.13	0.18	0.28	0.35	0.57	0.7	0.91	1.14	1.46	
60	100	-	-	-	-	-	-	0.1	0.15	0.21	0.32	0.39	0.59	0.83	1.02	1.3	1.65	
100	160	-	-	-	-	-	-	-	0.17	0.24	0.35	0.47	0.67	0.95	1.18	1.5	1.93	
160	250	-	-	-	-	-	-	-	-	0.28	0.39	0.55	0.79	1.1	1.38	1.73	2.21	
250	400	-	-	-	-	-	-	-	-	-	0.43	0.63	0.91	1.26	1.58	1.97	2.52	

Table A.3 SFSA 2000 for steel casting tolerance long-production series.

Conditions	Select Tolerance Grades
All sand molding process fully capable, most appropriate for large castings	CT 12-14
Appropriate for most casting types and sand molding processes	CT 10-12
Within process capabilities, but not appropriate for all casting types and sand molding processes	CT 8-10
Investment Casting	CT 5-7

Table A.4 SFSA 2000 steel casting tolerances for short-production series steel castings

Conditions	Select Tolerance Grades
All sand molding process fully capable, most appropriate for large castings	CT 13-15
Appropriate for most casting types and sand molding processes	CT 11-13
Within process capabilities, but not appropriate for all casting types and sand molding processes	CT 9-11