The following pages contain some considerations and recommendations that should be used when designing V-Process castings that will be produced at TPi Arcade Castings. When in doubt, it is important to send in a drawing, either by hard copy, fax, E-Mail or CD, for some direction in the design process.

When any casting design is being considered, it is important to involve both the casting producer and the machining source as early in the design process as possible. Even if the specific type of casting (sand, die, V-Process, etc.) has not been determined, working with one or more casting suppliers will always be beneficial to determine the best casting process for the application. Having the casting and machining source working together will result in the best approach to get to the desired results in the final finished part.

At TPi Arcade Castings we utilize Project Engineers. These individuals initially work closely with our customers to ensure close coordination and communication between the customer and internal personnel. The Project Engineers will also work closely with our Sales Representative to ensure follow through on a project so that we are involved with a project from the beginning.

TPi Arcade, Inc. /7888 Route 98/Arcade, New York 14009/Ph.: (585) 492-0122 • Fax: (585) 492-0169

Sales@tpicast.com

WALL SECTION THICKNESS

TPi Arcade can produce walls as thin as .090 inch. However, this is the exception and we are much more comfortable at and above .125 inch, with .125 — .150 inches being the norm.

The smaller the part, the thinner the wall section can be. Other factors determining minimum wall section are the alloy (A356 is best), ability to flow the metal into the thin section and the amount of thick/thin section transitions.

There is no upper limit to the wall section that TPi Arcade can pour.

MOLD SIZES

At TPi Arcade, we produce V-Process castings in the following mold sizes. a)
36” x 36” x 9/9”

b) 36” x 48” x 12/12"
c) 24” x 36” x 12/12”
d) 15” x 20” x 9/9”

As a rule of thumb, we need a minimum of 2-5 inches in the length and width for the gating system depending on the shape and size of the part. If a pattern has an offset or irregular parting, then additional room around the pattern is required.

When in doubt, do not assume a part will fit. Send the drawing in for our evaluation.

The number of impressions that can fit into a mold is determined by the size of the part and the gating system required. Again, when in doubt, do not assume a part will fit. Send the drawing in for our evaluation.

TOLERANCES

Our stated V-Process linear tolerances are:

a) ± .010 inch for the first inch
b) ± .002 inch for each additional inch
c) Additional ± .010 to ± .020 inch across the parting line
d) Flatness tolerance of .003 inch per inch
e) Additional tolerances may apply in cored areas

The largest variable when constructing a pattern is the shrink factor. We usually use a shrink factor of .012 inch per inch for A356 and SR319 aluminum alloys. TPi Arcade only use A356 & SR319. The thinner the wall section, the less a part will shrink.

As a rule of thumb, once the pattern is made and the samples are inspected, we can hold about half of the above tolerances for features that are made in the same half of the mold.

The amount of additional tolerance required for cored areas is determined by the size and shape of the core.

The flatness that we can hold depends on the design of the part (how thick is the part, stiffening ribs, etc.). Also it depends on the flatness that the customer wants and is willing to pay for. How much time we should spend on straightening and inspecting the part during the cleaning process is determined partially by the flatness that the drawing calls for.

Look to the parting line variation as a key concern. Your understanding of this variable is critical to assessing repeatability in casting and machining design and functionality.

FILM STRETCH

One of the points to consider when designing a part for the V-Process is the film stretch. Specifically this is the amount the plastic film needs to stretch to form over and into features of the pattern.

The first step in producing a V-Process mold is the vacuum forming of a thin sheet of heated plastic film over the V-Process pattern. As the film contacts a point on the pattern and is drawn down to form other features of the pattern, the film will be stretched as it forms the features.

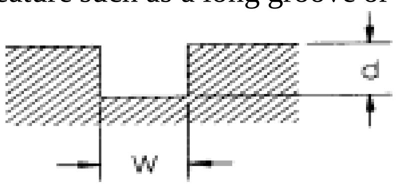
The safe limit for the film stretch ratio is 5 to 1. That is the amount that the film will need to stretch when it is drawn over the pattern.

This comes into play when the film is drawn into features such as cast holes and heatsink fins.

The thickness of the plastic used is typically .005 inch. Therefore, if the film is stretched to a 5 to 1 ratio, the film will be reduced to a thickness of .001 inch. Any thickness less than the .001 inch will generally result in a mold that is not capable of producing a good casting.

The calculations to determine the film stretch ratio are explained below.

For a feature such as a long groove or the spacing between fins of a heat sink:



The width of the opening is w. The depth of the opening is d. The formula is (2(d) +W) = Film stretch ratio

For a circular hole:

The radius of the hole is r . The depth of the hole is h . The diameter of the hole is d .
Film stretch ratio = $(\pi r^2 + \pi d h) / \pi r^2$

The above information is a design guide only. There may be situations where the total design of the part can exceed the 5 to 1 stretch by using thicker plastic film or other "tricks of the trade". On the other hand there may be situations that, due to the proximity of various features to each other the film, cannot be stretched even though the ratio does not exceed 5 to 1.

In all cases, if you have any questions concerning film stretch or any other V-Process design criteria, you should contact TPI Arcade Castings for assistance.

CORES AND LOOSE PIECES

The V-Process can use cores that are similar to a sand casting core with the exception that we coat the core with a ceramic wash. The purpose of this is to seal the coarser core sand so when a vacuum is pulled on the core the aluminum is not sucked into the core resulting in a "burn in" condition.

In certain situations we are able to use sliding loose pieces in the pattern equipment to form features that have negative draft in place of a core. This is usually desirable since they:

a) Provide a better surface finish than a cored surface. The finish will be the V-Process finish.

b) Reduce the piece price since there is no need to make, set and remove a core along with the disposal cost of the core sand.

c) Can hold the loose piece area to the V-Process tolerance without applying additional core tolerance.

The ability to use a loose piece depends on the shape of the part and the parting line of the pattern. Send us the drawing to see if loose pieces are possible.

DATUMS

TPi Arcade strongly recommends that our customers use the 3-2-1 datum system for both the casting and machining drawings. This system will help eliminate confusion and problems in inspection of both machined and non-machined castings.

The basics are covered in the "Considerations for the Machining of Aluminum Castings" later in this document.

We would like to see separate casting and machining drawings. This helps eliminate confusion as to which surfaces get machined.

ALLOYS

TPi Arcade can pour either 95% or 5%.   The characteristics of aluminum alloys as copied from the "Standards for Sand and Permanent Mold Castings" handbook published by The Aluminum Association, Inc. is included in this document.

Almost all of the 356 we provide is to a T51 artificial age heat treatment. We can also provide T77 and T6 heat treatment of 356 alloy.

T6 is commonly required for MIL SPEC work or high strength applications. High-grade commercial applications that are primarily cosmetic can generally use T5.

DRAFT

The V-Process is unique in that it does not require any draft angle. This is due to the lubricity of the plastic film that allows for the mold to be stripped from the pattern without the friction of the sand against the pattern. The vacuum that was applied during the film forming operation is released and the vacuum is then applied to the mold. This causes a slight, controlled expansion or contraction of the mold features.

The advantages of the zero draft capabilities are:

〈 Constant Wall Thickness for weight reductions and aesthetic appeal.
〈 Possible elimination of machining off of the draft for clearances for mating parts and assemblies.
〈 Allows for simple and more accurate fixturing for machining and inspection.
〈 Total Tolerance range remains for the actual feature, not the feature plus draft. Draft does not use up the tolerance.
〈 Design/Drafting is less complex. Calculations and depictions are simplified.
〈 Pattern construction is more accurate and efficient. Greatly enhances the ability to CNC machine the patterns.

POROSITY

No casting technique will insure that the parts produced are free of casting imperfections or porosity. These imperfections are the result of a multitude of factors, including the casting design.

All other factors being equal, the V-Process will tend to produce a part with a minimum amount of porosity. One of the reasons for this is the dry sand that is used. The sand has no moisture to cause steam and also no chemical binder to cause out-gassing. The mold itself is constantly under a strong vacuum. Therefore, any gases that may be created are not trapped but pulled out through the sand by the vacuum.

SURFACE FINISH

The V-Process will provide a much better surface finish than a typical sand or permanent mold casting. At TPi Arcade we are running between a 125 and 150 RMS surface finish.

Most castings get a light blast after cleaning. However, on some parts we can do a vibratory finish or buff certain surfaces if a different surface is required. The final surface treatment and criteria generally determine the cleaning requirements.

GATE LOCATION

The V-Process has the advantage of using wood for the gating system. This means that the gating system, although permanent, can be easily and quickly changed.

Typically gate and vent locations are not specified on the customer's drawing. We take care not to locate the gating on datum points or on surfaces that are critical from a dimensional or aesthetic standpoint.

RADII

Good casting practice requires the use of fillets in castings. TPi Arcade recommends a minimum of .060" radius. There is a correlation between the metal wall thickness and the radii.

PROCESS DEVELOPMENT

When producing a casting for the first time there is always a certain amount of trial and error involved in developing a gating system and foundry process that will achieve the required level of soundness. Generally, the more complex the part or the more drastic the change in metal thickness, the greater the challenge and the less predictable the outcome.

Examination by x-ray has proven to be one of the most effective methods available for determining casting soundness. Without x-ray, the foundry is forced to wait until the part is machined to visually examine the exposed surfaces. The foundry is provided with complete and instant feed back, which ultimately reduces development time. TPi Arcade utilize both Phillips Real-Time X-Ray (no film) and standard film X-Ray.

COST DRIVERS

The following will describe areas of activity that produce the greatest influence on the cost of a part.

Casting:
a) Number of impressions per mold
b) Number of molds produced per shift
c) Amount and complexity of cores required
d) Amount of cleaning, grinding, buffing, blasting required
e) Weight of casting
f) Heat treat specification
g) Scrap factor

Machining:
a) Set-up time
b) Cycle time
c) Hardware required
d) Surface finish of part (RMS)
e) Fixturing
f) Programming
g) Complexity of part

Generic:
a) Specifications
b) Packaging
c) Finishing specifications — chromate, plate, paint, powder coat, etc.
d) Tolerances
e) Accuracy of database provided by customer

CONSIDERATIONS FOR THE MACHINING OF ALUMINUM CASTINGS

Many designers/engineers utilize "Geometric Dimensioning and Tolerancing" (GDT) practices. Below are some considerations related to the application of these practices to the machining of aluminum castings (terms that are boldfaced are defined on the following two pages).

It is Tpi Arcade's experience that some explanation of the impact of the use of GDT on parts to be cast and subsequently machined is useful.

A datum feature must be an actual feature of a part. Center lines and center planes are theoretical. They do not exist as features on an actual part and, therefore, may not be used as datum features.

A datum is selected on the basis of its geometric relationship to other features and the functional requirements of the design. For mating parts, it is usually desirable to select corresponding features on each part as datum features to ensure proper interface in assembly.

Datum features must be readily discernible on an actual part, be accessible and be of sufficient size or extent to permit their use for manufacturing and inspection activities.

A casting is typically a framework to hold together places to fasten other components. The cast surfaces are generally secondary in accuracy requirements to the areas machined (threaded holes, reamed holes, milled slots, grooves, surfaces). This leads to the need for two datum reference frames.

Selected datum features of castings may be used temporarily for the establishment of machined surfaces to serve as permanent datum features. Such temporary datum features may or may not be subsequently removed by machining. Permanent datum features should be physical elements not appreciably changed by subsequent machining operations.

Datum targets, as applicable on cast or machine surfaces, should be chosen with the following points in mind whenever possible:

- be a feature on the part
- be accessible
- be capable of being clamped properly
- not be located on cored surfaces
- datum targets in any one datum plane should not cross the mold parting line

There are many good reasons, as outlined in ANSI Y14.5-1982, for proceeding in the above manner. Additionally, good machining practices dictate the need for part rigidity during machining which, in turn, requires good fixturing and clamping. Clamping should be done on the ABC datum reference frame targets and in such a manner as to machine as many of the required surfaces as possible. This reduces the number of setups required to complete the part and helps to reduce the amount of variation from casting to casting. Clamping must be sufficient to hold the part in place while resisting machining forces, but not so tightly or on a surface that will cause deflection.

This leads to another major area of concern — true position callouts. Designers understandably want the highest quality possible in the parts they create. This sometimes leads to unrealistically small true position callouts on a drawing.

Experience and observation have shown that a number of factors impact on the ability to hold true position.

- Deflection caused by poor clamping circumstances, flimsy casting structure, machining forces and thermal effects (both the heat treatment of the casting and the ambient temperature conditions during machining versus those in which the casting is used).

- Machine tool capability; a manufacturer may claim repeatability of ±.0002 inch. This may well be true at the time the machine tool was built and under "lab" (non-machining) conditions. Actual manufacturing conditions and age of the equipment can erode this capability considerably.

- Post-machining operations such as plating, anodizing and painting if not properly controlled or anticipated will affect true position (among other things).

Consequently, a true position callout of .002 inch or smaller is typically impractical. With all of the above in mind, a callout of .005 inch for true position will generally be a far more practical and economical value to use. TPi Arcade will accept orders which specify true position callouts of smaller than .005 inch only on an "aim-for" basis.

DEFINITIONS: (Taken from ANSI Y14.5M-1982)

Datum — A theoretically exact point, axis or plane derived from the true geometric counterpart of a specified datum feature. A datum is the origin from which the location or geometric characteristics of features of a part are established.

Datum Reference Frame — A system of three mutually perpendicular datum planes or axes established from datum features as a basis for dimensions for design, manufacture and verification. It provides complete orientation for the feature involved.

Datum Plane — Theoretically exact plane established by the extremities or contacting points of the datum feature (surface) with a simulated datum plane (surface plate or other checking device).

Datum Feature — An actual feature of a part that is used to establish a datum.

Datum Target — A point, line or small area specified on the part to establish a datum.

True Position — A term used to describe the perfect (exact) location of a point, line or size feature in relationship with a datum reference or other feature.

The suggested hierarchy and identification of datum reference frames and their constituents, as follows:

"A" datum plane — The primary datum plane consisting of datum targets Al, A2 and A3.

"B" datum plane — The secondary datum plane consisting of datum targets B1 and B2.

"C" datum plane — The tertiary datum plane consisting of datum target Cl.

"A", "B", "C" (ABC) datum planes are mutually perpendicular, are assigned to or utilized with cast features only on an unmachined or machined casting and may be temporary.

"D" datum plane — The primary datum plane consisting of datum target D1, D2 and D3.

"E" datum plane — The secondary datum plane consisting of datum targets El and E2.

"F" datum plane — The tertiary datum plane consisting of datum target F 1.

DEF datum planes are also mutually perpendicular, are assigned to or utilized with machined features on a machined casting only, are permanent and are typically assigned a "start" dimension corresponding to cast datum features.

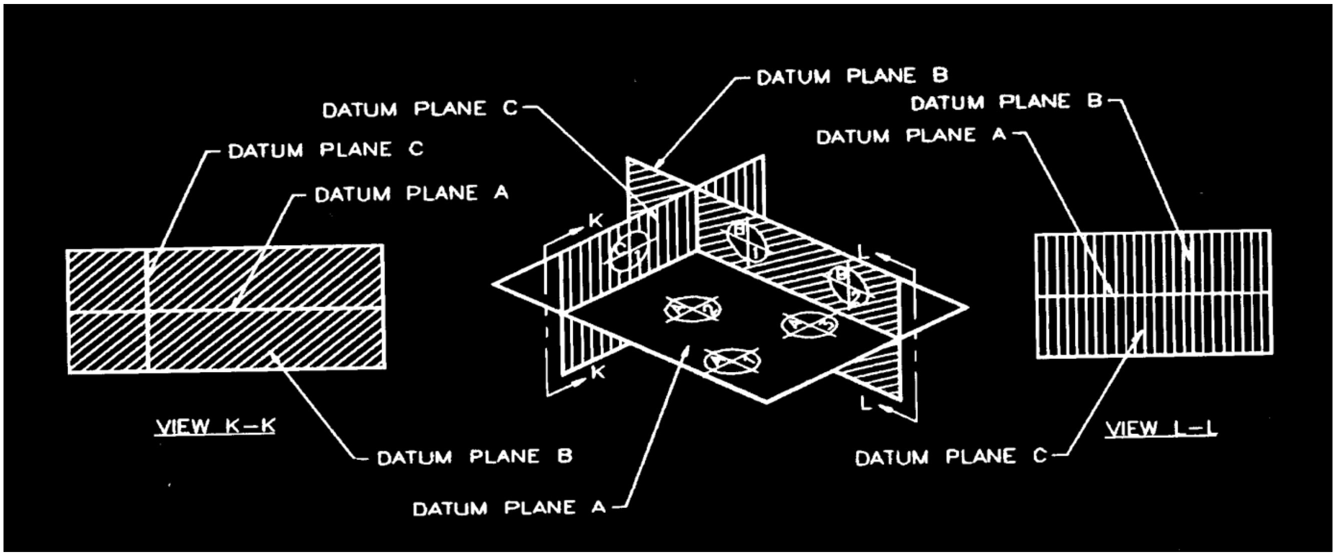
Please be advised that TPi Arcade is ready to help any customer in understanding how the above concepts affect the design, manufacture and cost effectiveness of their parts. If there are questions to be answered or issues to be resolved, contact your Project Engineer for further information.

A "DATUM" is a feature or group of features of a part, selected for use as a base from which other features or points are located within specified limits.

To achieve consistency in the manner in which measurements are made in all stages of production, i.e., pattern making, casting layout, tooling layout, etc., a system known as target points or datum lines, or datum planes has been devised. For the purposes of this standard, "target point" and "tooling point" are synonymous. This system relates all significant dimensions to a common reference (datum plane). It is strongly recommended that those points or planes from which inspection and/or machining layouts are started, be indicated on the drawing by symbol or other means. Where datum planes or target points are not indicated, they shall be selected by the foundry, which will choose surfaces formed by the most stable portion of the mold. Such designations tend to control the accumulation of tolerances in addition to their prime purpose of establishing a common location from which to work. It is preferred that they be surfaces not affected by mold parting. Also, the surfaces at which gates and risers are to be placed are unsuitable as target points as a result of trimming and rough grinding operations. Target points should be avoided if possible on cored or tapered surfaces. They should be located close to the extremities of the casting whenever possible to eliminate variations in alignment due to projecting small surface irregularities.

The designer of a casting, the tooling engineer and the foundry should work together in establishing target points or datum planes because they directly influence casting cost not only from the tooling standpoint but also from the foundry standpoint.

Fig. 1 Schematic illustration showing the perpendicular relations among the three planes in a sy



TPi Arcade, Inc.

ENGINEERING SERVICES

Where Challenging Designs Become Reality

TPi Arcade would like to introduce you to some of the services we offer. You may find your Engineering Department overloaded with new product development and your Marketing Department trying to release a product in a hurry. We can help. Working closely with your engineers we can help in the design for our processes, often reducing part costs. Using your computer database we can make part drawings, build patterns, design fixtures and program the machine tools concurrently. This decreases lead-time substantially enabling you to get your product to the market quicker.

BENEFITS OF USING TPI ARCADE'S ENGINEERING SERVICES

〈 Our engineering staff has the knowledge and equipment available to allow TPi Arcade to use your computer database to generate patterns and machine part programs and to assist you with your design.
〈 A highly skilled staff that includes manufacturing engineers.
〈 Thorough working knowledge of ANSI Y14.5M-1982 specifications.
〈 These services add up to a rapid prototyping system.

ADVANTAGES TO ELECTRONIC DATA TRANSFER

Electronic data transfer (EDT) aids in your product development through:
〈 Faster print to part time
〈 Rapid development
〈 A timely handling of revision and design changes
〈 Elimination of reproduction errors
〈 The use of concurrent engineering
If you think we could help or if you have any questions, please call us or send information regarding your requirements so we can be of assistance.

PRODUCT DATABASES

TPi Arcade can use the CAE (computer-aided engineering) design work you have done with your system to create a model, hog-out, pattern and/or a machined casting. This is done by using one of many translation protocols. Most systems have this capability.

TPi Arcade can handle most CAD file formats including IGES, Pro-E, Solid works, Parasolid, etc.

Stereolithography (STL) files can be used for quoting by TPi Arcade. However, TPi Arcade cannot use stereolithography files for pattern making. TPI's process for creating patterns creates much smoother, finished-product quality castings and the use of STL would prohibit the production of the best possible casting.

Once the process path is clarified, it is extremely important that the database submitted to TPi Arcade is accurate. It may seem obvious and, therefore, unnecessary to address, but our experience shows otherwise. There is a significant amount of cost associated with discrepancies, particularly if not found until well into the process. Delivery problems can also occur if the database is inaccurate.

If you have any questions about which file format to use, please call TPi Arcade (585) 492-0122 Project Engineer between 8:00 am and 5:00 pm Eastern Time.

FILE TRANSFERS

Visit us on the Internet at www.tpicast.com .

TPi Arcade, Inc.

CHEMICAL COMPOSITION LIMITS FOR COMMONLY USED SAND AND PERMANENT MOLD CASTING ALLOYS [1] [2]

Alloy	Product [3]	Silicon	Iron	Copper	Manganese	Magnesium	Chromiun	Nickel	Zinc	Titanium	Others	
											Each	Total [0]
201.0	S	0.10	0.15	4.0-5.2	0.20-0.50	0.15-0.55	-	-	-	0.15-0.35	0.05 [8]	0.10
204.0	S&P	0.20	0.35	4.2-5.0	0.10	0.15-0.35	-	0.05	0.10	0.15-0.30	0.05 [9]	0.15
208.0	S&P	2.5-3.5	1.2	3.5-4.5	0.50	0.10	-	0.35	1.0	0.25	-	0.50
222.0	S&P	2.0	1.5	9.2-10.7	0.50	0.15-0.35	-	0.50	0.8	0.25	-	0.35
242.0	S&P	0.7	1.0	3.5-4.5	0.35	1.2-1.8	0.25	1.7-2.3	0.35	0.25	0.05	0.15
295.0	S	0.7-1.5	1.0	4.0-5.0	0.35	0.03	-	-	0.35	0.25	0.05	0.15
296.0	P P	2.0-3.0	1.2	4.0-5.0	0.35	0.05	-	0.35	0.50	0.25	-	0.35
308.0	S&P	5.0-6.0	1.0	4.0-5.0	0.50	0.10	-	-	1.0	0.25	-	0.50
319.0	S	5.5-6.5	1.0	3.0-4.0	0.50	0.10	-	0.35	1.0	0.25	-	0.50
328.0	P	7.5-8.5	1.0	1.0-2.0	0.20-0.6	0.20-0.6	0.35	0.25	1.5	0.25	-	0.50
332.0	P	8.5-10.5	1.2	2.0-4.0	0.50	0.50-1.5	-	0.50	1.0	0.25	-	0.50
333.0	P	8.0-10.0	1.0	3.0-4.0	0.50	0.05-0.50	-	0.50	1.0	0.25	-	0.50
336.0	S&P	11.0-13.0	1.2	0.50-1.5	0.35	0.7-1.3	-	2.0-3.0	0.35	0.25	0.05	-
354.0	S&P	8.6-9.4	0.20	1.6-2.0	0.10	0.40-0.6	-	-	0.10	0.20	0.05	0.15
355.0	S&P	4.5-5.5	0.6 [4]	1.0-1.5	0.05 [4]	0.40-0.6	0.25	-	0.35	0.25	0.05	0.15
C355.0	S&P	4.5-5.5	0.20	1.0-1.5	0.10	0.40-0.6	-	-	0.10	0.20	0.05	0.15
356.0	S&P	6.5-7.5	0.6 [4]	0.25	0.35 [4]	0.20-0.45	-	-	0.35	0.25	0.05	0.15
A356.0	S&P	6.5-7.5	0.20	0.20	0.10	0.25-0.45	-	-	0.10	0.20	0.05	0.15
357.0	S&P	6.5-7.5	0.15	0.05	0.03	0.45-0.6	-	-	0.05	0.20	0.05	0.15
A357.0	S&P	6.5-7.5	0.20	0.20	0.10	0.40-0.7	-	-	0.10	0.04-0.20	0.05 [3]	0.15
359.0	S&P	8.5-9.5	0.20	0.20	0.10	0.50-0.7	-	-	0.10	0.20	0.05	0.15
443.0	S&P	4.5-6.0	0.8	0.6	0.50	0.05	0.25	-	0.50	0.25	-	0.35
B443.0	P	4.5-6.0	0.8	0.15	0.35	0.05	-	-	0.35	0.25	0.05	0.15
A444.0	S	6.5-7.5	0.20	0.10	0.10	0.05	-	-	0.10	0.20	0.05	0.15
512.0	P	1.4-2.2	0.6	0.35	0.8	3.5-4.5	0.25	-	0.35	0.25	0.05	0.15
513.0	S	0.30	0.40	0.10	0.30	3.5-4.5	-	-	1.4-2.2	0.20	0.05	0.15
514.0	S	0.35	0.50	0.15	0.35	3.5-4.5	-	-	0.15	0.25	0.05	0.15
520.0	S&P	0.25	0.30	0.25	0.15	9.5-10.6	-	-	0.15	0.25	0.05	0.15
535.0	S&P	0.15	0.15	0.05	0.10-0.25	6.2-7.5	-	-	-	0.10-0.25	0.05 [6]	0.15
705.0	S&P	0.20	0.8	0.20	0.40-0.6	1.4-1.8	0.20-0.40	-	2.7-3.3	0.25	0.05	0.15
707.0	S	0.20	0.8	0.20	0.40-0.6	1.8-2.4	0.20-0.40	-	4.0-4.5	0.25	0.05	0.15
710.0	P S	0.15	0.50	0.35-0.65	0.05	0.6-0.8	-	-	6.0-7.0	0.25	0.05	0.15
711.0	S&P	0.30	0.7-1.4	0.35-0.65	0.05	0.25-0.45	-	-	6.0-7.0	0.20	0.05	0.15
712.0	S	0.30	0.50	0.25	0.10	0.50-0.65	0.40-0.6	-	5.0-6.5	0.15-0.25	0.05	0.20
713.0	S&P	0.25	1.1	0.40-1.0	0.6	0.20-0.50	0.35	0.15	7.0-8.0	0.25	0.10	0.25
771.0	S&P	0.15	0.15	0.10	0.10	0.8-1.0	0.06-0.20	-	6.5-7.5	0.10-0.20	0.05	0.15
850.0	S&P	0.7	0.7	0.7-1.3	0.10	0.10	-	0.7-1.3	-	0.20	- [7]	0.30
851.0		2.0-3.0	0.7	0.7-1.3	0.10	0.10	-	0.30-0.7	-	0.20	- [7]	0.30
852.0		0.40	0.7	1.7-2.3	0.10	0.6-0.9	-	0.9-1.5	-	0.20	- [7]	0.30

1 The alloys listed are those which have been included in Federal Specifications QQ-A-596d, ALUMINUM ALLOYS PERMANENT AND SEMIPERMANENT MOLD CASTINGS, QQ-A-601E, ALUMINUM ALLOY SAND CASTINGS, and Military Specification MIL-A-21180c, ALUMINUM ALLOY CASTINGS, HIGH STRENGTH. Other alloys are registered with The Aluminum Association and are available. Information on these should be requested from individual foundries or ingot suppliers.

2 Except for "Aluminum" and "Others" analysis normally is made for elements for which specific limits are shown. For purposes of determining conformance to these limits, an observed value or calculated value obtained from analysis is rounded off to the nearest unit in the last right hand place of figures used in expressing the specified limit, in accordance with the following:
When the figure next beyond the last figure or place to be retained is less than 5, the figure in the last place retained should be kept unchanged.
When the figure next beyond the last figure or place to be retained is greater than 5, the figure in the last place retained should be increased by 1.
When the figure next beyond the last figure or place to be retained is 5 and
1. there are no figures or only zeros, beyond this 5, if the figure in the last place to be retained is odd, it should be increased by 1;
2. if even, it should be kept unchanged; if the 5 next beyond the figure in the last place to be retained is followed by any figures other than zero, the figure in the last place retained should be increased by one; whether odd or even.

3 S = Sand Cast P =Permanent Mold Cast

4 If iron exceeds 0.45 percent, manganese content shall not be less than one-half the iron content.

5 Also contains 0.04-0.07 percent beryllium.

6 Also contains 0.003-0.007 percent beryllium, boron 0.005 percent maximum.

7 Also contains 5.5-7.0 percent tin.

8 Also contains 0.40-1.0 percent silver.

9 Also contains 0.05 max. percent tin.

0 The sum of those "Others" metallic elements 0.010 percent or more each, expressed to the second decimal before determining the sum.

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MECHANICAL PROPERTY LIMITS FOR COMMONLY USED ALUMINUM SAND CASTING ALLOYS [1]

Minimum Properties

Alloy	Temper [2]	Tensile Strength: Ultimate Ksi	Ultimate (Mpa)	Yield (0.2% Offset) Ksi	Yield (Mpa)	% Elongation in 2" or 4 x Dia.	Typical Brinell Hardness [4] 500 – kfg Load 10mm Ball
201.0	T7	60.0	(414)	50.0	(345)	3.0	110-140
204.0	T4	45.0	(310)	28.0	(193)	6.0	-
208.0	F	19.0	(131)	12.0	(83)	1.5	40-70
222.0	0	23.0	(159)	-	-	-	65-95
222.0	T61	30.0	(207)	-	-	-	100-130
242.0	0	23.0	(159)	-	-	-	55-85
242.0	T571	29.0	(200)	-	-	-	70-100
242.0	T61	32.0	(221)	20.0	(138)	-	90-120
242.0	T77	24.0	(165)	13.0	(90)	1.0	60-90
295.0	T4	29.0	(200)	13.0	(90)	6.0	45-75
295.0	T6	32.0	(221)	20.0	(138)	3.0	60-90
295.0	T62	36.0	(248)	28.0	(193)	-	80-110
295.0	T7	29.0	(200)	16.0	(110)	3.0	55-85
319.0	F	23.0	(159)	13.0	(90)	1.5	55-85
319.0	T5	25.0	(172)	-	-	-	65-95
319.0	T6	31.0	(214)	20.0	(138)	1.5	65-95
328.0	F	25.0	(172)	14.0	(97)	1.0	45-75
328.0	T6	34.0	(234)	21.0	(145)	1.0	65-95
354 0	[3]	-	-	-	-	-	-
355.0	T51	25.0	(172)	18.0	(124)	-	50-80
355.0	T6	32.0	(221)	20.0	(138)	2.0	70-105
355.0	T7	35.0	(241)	-	-	-	70-100
355.0	T71	30.0	(207)	22.0	(152)	-	60-95
C355.0	T6	36.0	(248)	25.0	(172)	2.5	75-105
356.0	F	19.0	(131)	-	-	2.0	40-70
356.0	T51	23.0	(159)	16.0	(110)	-	45-75
356.0	T6	30.0	(207)	20.0	(138)	3.0	55-90
356.0	T7	31.0	(214)	29.0	(200)	-	60-90
356.0	T71	25.0	(172)	18.0	(124)	3.0	45-75
A356.0	T6	34.0	(234)	24.0	(165)	3.5	70-105
357.0	[3]	-	-	-	-	-	-
A357.0	[3]	-	-	-	-	-	-
359 0	[3]	-	-	-	-	-	-
443.0	F	17.0	(117)	7.0	(49)	3.0	25-55
B443.0	F	17.0	(117)	6.0	(41)	-	35-65
512.0	F	17.0	(117)	10.0	(69)	6.0	35-65
514.0	F	22.0	(152)	9.0	(62)	12.0	60-90
520.0	T4 [5]	42.0	(290)	22.0	(152)	-	
535.0	F or T5	35.0	(241)	18.0	(124)	9.0	60-90
705.0	F or T5	30.0	(207)	17.0	(117)	5.0	50-80
707 0	T5	33.0	(228)	22.0	(152)	2.0	70-100
707.0	T7	37.0	(255)	30.0	(207)	1.0	65-95
710.0	F or T5	32.0	(221)	20.0	(138)	2.0	60-90
712.0	F or T5	34.0	(234)	25.0	(172)	0	60-90
713.0	F or T5	32.0	(221)	22.0	(152)	3.0	60-90
771.0	T5	42.0	(290)	38.0	(262)	1.5	85-115
771.0	T51	32.0	(221)	27.0	(186)	3.0	70-100
771.0	T52	36.0	(248)	30.0	(207)	1.5	70-100
771.0	T53	36.0	(248)	27.0	(186)	1.5	-
771.0	T6	42.0	(290)	35.0	(241)	5.0	75-105
771.0	T71	48.0	(331)	45.0	(310)	2.0	105-135
850.0	T5	16.0	(110)	-	-	5.0	30-60
851.0	T5	17.0	(117)	-	-	3.0	30-60
852.0	T5	24.0	(165)	18.0	(124)	-	45-75

1 Values represent properties obtained from separately cast test bars and are derived from ASTM B-26, Standard Specification for Aluminum-Alloy Sand Castings; Federal Specification QQ-A-60le, Aluminum Alloy Sand Castings; and Military Specification MIL-A-21180c, Aluminum Alloy Castings,.High Strength. Unless otherwise specified, the average tensile strength, average yield strength and average elongation values of specimens cut from castings shall be not less than 75 percent of the tensile and yield strength values and not less than 95 percent of the elongation values given above. The customer should keep in mind that (1) some foundries may offer additional tempers for the above alloys, and (2) foundries are constantly improving casting techniques and, as a result, some may offer minimum properties in excess of the above.

2 F indicates "as cast° condition; refer to AA-CS-MI l for recommended times and temperatures of heat treatment for other tempers to achieve properties specified.

3 Mechanical properties for these alloys depend on the casting process. For further information consult the individual foundries.

4 Hardness values are given for information only; not required for acceptance.

5 The T4 temper of Alloy 520.0 is unstable; significant room temperature aging occurs within life expectancy of most castings. Elongation may decrease as much as 80 percent.

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Selection of an alloy for a particular application requires consideration not only of mechanical properties, but also of numerous other characteristics, such as behavior in the casting process or subsequent treatments in the course of manufacture and response to the environment conditions of service. The following table includes several significant characteristics that deserve consideration in the selection of an alloy. The characteristics are comparatively rated from 1 to 5 in decreasing order of performance.

Aluminum Alloy	S-Sand P-Permanent Mold Product	Fluidly	Resistance to Hot Cracking	Pressure Tightness	Normally Heat Treated	Strength at Elevated Tempera-atures	Corrosion Resistance	Machin-abilfty	Polishing	Anodizing Appearance	Weld-abilfty
201.0	S	3	4	3	Yes Yes	1	4	1	1	2	4
204.0	S&P	3	4	3	Optional	1	4	1	2	3	4
208.0	S	2	2	2	Yes	3	4	3	3	3	2
222.0	S&P	3	3	3	Yes	1	4	1	2	3	3
242.0	S&P	3	4	4	Yes	1	4	2	2	3	4
295.0	S	3	4	4	Yes	3	4	2	2	2	3
296.0	P	3	4	3	No	2	4	3	2	3	3
308.0	P	2	2	2	Optional	3	3	3	3	4	2
319.0	S&P	2	2	2	Optional	3	3	3	4	4	2
328.0	S	1	1	2	Yes	2	3	3	3	4	1
332.0	P	1	2	2	Optional	1	3	4	4	4	2
333.0	P	1	2	2	Yes	2	3	3	3	4	3
336.0	P	1	2	2	Yes	1	3	4	4	4	3
354.0	P	1	1	1	Yes	2	3	4	4	4	3
355.0	S&P	1	1	I	Yes	2	3	3	3	4	1
C355.0	S&P	1	1	I	Yes	2	3	3	3	4	1
356.0	S&P	1	1	1	Yes	3	2	3	4	4	1
A356.0	S&P	1	1	1	Yes	3	2	3	4	4	1
357.0	S	I	1	1	Yes	3	2	3	4	4	1
A357.0	S&P	1	1	1	Yes	2	2	3	4	4	1
359.0	S&P	1	2	2	No	2	2	4	4	4	1
443.0	S&P	1	1	1	No	4	3	5	4	4	1
B443.0	S&P	1	1	1	Optional	4	2	5	4	4	1
A444.0	P	1	1	1	No	4	2	5	4	4	1
512.0	S	3	3	4	No	3	1	2	2	2	3
513.0	P	4	4	4	No	3	1	1	1	1	3
514.0	S	4	4	5	Yes	3	1	1	1	1	3
520.0	S	4	4	5	Optional	5	1	1	1	1	4
535.0	S	5	4	5	No	3	1	1	1	1	4
705.0	S&P	4	4	4	No	4	2	1	2	2	4
707.0	S&P	4	4	4	No	4	2	1	2	2	4
710.0	S	4	5	4	Yes	4	4	1	2	2	4
711.0	P S	4	5	4	No	5	2	1	1	1	4
712.0	S&P	3	5	4	No	4	3	1	2	2	4
713.0	S	3	4	4	Yes	4	3	1	1	1	4
771.0	S&P	3	4	4	Yes	4	3	1	1	1	4
850.0	S&P	4	5	5	Yes	5	4	1	3	*	5
851.0	S&P	4	5	5	Yes	5	4	1	3		5
852.0		4	5	5		5	4	1	3	*	5

*Information not available.

See next page for brief description of column headings. (Reprinted from the Aluminum Association Standards Handbook)

CHARACTERISTICS OF ALUMINUM ALLOYS

Fluidity is equivalent to "mold-filling" capability. It is measured by the distance a molten alloy will flow at a given pouring temperature before freezing.

Resistance to Hot Cracking is the property of an alloy to withstand stresses from contraction while cooling through the final ("hot short") stage of solidification.

Pressure Tightness is the degree of soundness attainable in a casting as indicated by the absence of leakage, through its walls or sections, of air or other media under pressure.

Response to Heat Treatment is a characteristic dependent upon composition. Some of the alloys listed as "not normally heat treated" may show some improvement of properties when heat treated. Moreover, alloys listed as normally heat treated are frequently used without heat treatment if their as-cast properties are adequate for a specific application.

Corrosion Resistance is the resistance of alloys to loss of volume strength and surface appearance upon exposure to various environments. The comparative ratings given here are based in general upon performance in various industrial or sea cost atmospheres. Exposures to specific corroding agents should be investigated in further detail.

Strength at Elevated Temperatures is a rating based upon tests made at temperatures up to 500°F after prolonged exposure at such temperatures.

Machinability is based upon ease of cutting, chip characteristics, quality of finish and tool life. For the heat treated alloys, the ratings are based upon the T6 temper. Naturally aging alloys are rated after room temperature aging to their stable condition.

Polishing characteristics is a composite rating based on the ease and speed of polishing, and finish quality, after various standard polishing techniques.

Anodizing Appearance is based upon visual examination after a standard anodizing treatment.

Weldability rating is based upon the ease of joining parts by gas and arc welding and the quality of the final welded joint. Brazing, a related process, is applicable to some of the 7XX.X series alloys which have the unique property of withstanding the brazing temperature and regaining their original strength after room temperature aging.

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Standards for Aluminum Sand and Permanent Mold Castings Handbook, 13th Edition.)

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V-PROCESS CASTING TOLERANCES

STANDARD		METRIC	
(inches) Note: Add .010 To All Parting Line Dimensions		(millimeters) Note: Add .25 To All Parting Line Dimensions	
Dimension	**Tolerance**	**Dimension**	**Tolerance**
0 - .999	+/- .010	0.0 - 25.37	+/-± .25
1 - 1.999	+/- .012	25.4 - 50.77	+/-± .30
2 - 2.999	+/- .014	50.8 - 76.17	+/-± .36
3 - 3.999	+/-± .016	76.2 - 101.57	+/-± .41
4 - 4.999	+/-± .018	101.6 - 126.97	+/-± .46
5 - 5.999	+/-± .020	127.0 - 152.37	+/-± .51
6 - 6.999	+/-± .022	152.4 - 177.77	+/-± .56
7 - 7.999	+/-± .024	177.8 - 203.17	+/-± .61
8 - 8.999	+/-± .026	203.2 - 228.57	+/-± .66
9 - 9.999	+/-± .028	228.6 - 253.97	+/-± .71
10 - 10.999	+/-± .030	254.0 - 279.37	+/-± .76
11 - 11.999	+/-± .032	279.4 - 304.77	+/-± .81
12 - 12.999	+/-± .034	304.8 - 330.17	+/-± .86
13 - 13.999	+/-± .036	330.2 - 355.57	+/-± .91
14 - 14.999	+/-± .038	355.6 - 380.97	+/-± .97
15 - 15.999	+/-± .040	381.0 - 406.37	+/-± 1.02
16 - 16.999	+/-± .042	406.4 - 431.77	+/- 1.07
17 - 17.999	+/-± .044	431.8 - 457.17	+/-± 1.12
18 - 18.999	+/- .046	457.2 - 482.57	+/-± 1.17
19 - 19.999	+/-± .048	482.6 - 507.97	+/-± 1.22
20 - 20.999	+/-± .050	508.0 - 533.37	+/-± 1.27
21 - 21.999	+/-± .052	533.4 - 558.77	+/- 1.32
22 - 22.999	+/-± .054	558.8 - 584.17	+/- 1.37
23 - 23.999	+/-± .056	584.2 - 609.57	+/- 1.42
24 - 24.999	+/-± .058	609.6 - 634.97	+/- 1.47
25 - 25.999	+/-± .060	635.0 - 660.37	+/- 1.52
26 - 26.999	+/- .062	660.4 - 685.77	+/- 1.57
27 - 27.999	+/- .064	685.8 - 711.17	+/- 1.63
28 - 28.999	+/- .066	711.2 - 736.57	+/- 1.68
29 - 29.999	+/- .068	736.6 - 761.97	+/- 1.73
30 - 30.999	+/- .070	762.0 -787.37	+/- 1.78
31 - 31.999	+/- .072	787.4 - 812.77	+/- 1.83
32 - 32.999	+/- .074	812.8 - 838.17	+/- 1.88
33 - 33.999	+/- .076	838.2 - 863.57	+/- 1.93
34 - 34.999	+/- .078	863.6 - 888.97	+/- 1.98

〈 Cored areas may require additional tolerances.

〈 Depending upon the design, repeatability of dimensions will generally be held within a closer range than these general tolerances.

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COMPARISON OF LINEAR TOLERANCES AS CAST

(IN INCHES)

Casting Method	3 Inches	6 Inches	12 Inches	24 Inches	Parting Line Shift In Inches	Surface Finish As Cast (RMS)
V-Process	± .014	± .020	± .032	± .056	± .010	125 - 150
Sand Cast	± .030	± .035	± .060	± .125	± .020 - .060	250 - 500
Die Cast	± .006	± .009	± .015	± .027	± .015	30 - 60
Plaster Mold	± .015	± .024	± .042	± .078	± .015	90 - 125
Investment Cast	± .009	± .015	± .027	± .051	± .000	90 -1 2 5
Permanent Mold	± .019	± .025	± .037	± .061	± .010 - .025	50 - 200

COMPARISON TO OTHER PROCESSES

The information in the following chart compares how the V-Process compares to other casting processes. (F) indicates the V-Process compares favorably, (U) indicates unfavorable and a (C) indicates close comparison.

	Molding Processes				
	Sand	**Die**	**Plaster**	**Investment**	**Permanent**
Pattern price	U	F	C	C	F
Pattern life	F	F	F	F	F
Pattern revisions	C	F	C	C	F
Piece price	U	U	F	F	U
Surface finish	F	U	U	U	F
Tolerances	F	U	C	U	C
Porosity	F	F	F	C	U
Wall thickness	F	C	U	U	F

The above comparison depends on the casting supplier, metals cast, quantity, casting application required and technical/engineering services provided.

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