

10 RULES FOR GOOD CASTINGS

This renowned foundry scientist shares with metalcasters his guidelines for 'the reliable production of reliable castings.'

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The last few years have witnessed an unprecedented increase in our understanding of the casting process. Thus, as understanding has increased, the list of requirements has been steadily amended as they have become known. Starting from an initial list of four rules, 10 rules have now been identified that incorporate the latest technology for producing reliable castings. These are just the start. Additional rules may exist, but they remain to be further researched and clarified.

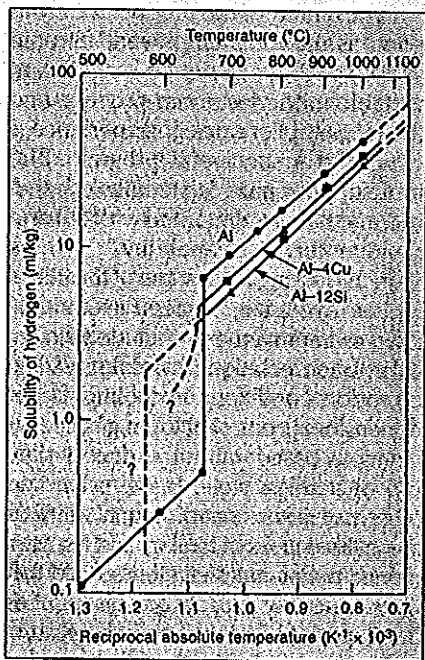
The 10 rules that follow are proposed as necessary, but not, of course, sufficient. They should be used in addition to existing conventional technical specifications such as alloy type, strength and traceability via ISO 9000, etc., and

other conventional foundry controls such as casting temperature, etc.

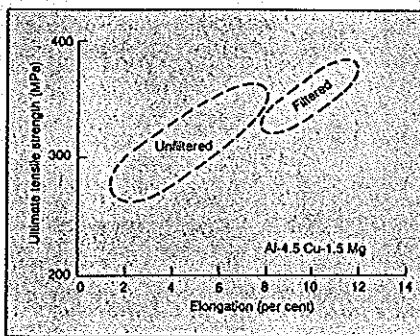
Although not yet tested on all cast materials, there are fundamental reasons for believing that the rules have general validity, and are applicable for all types of metals and alloys, including those based on aluminum, zinc, magnesium, cast irons, steels, air- and vacuum-cast nickel, cobalt and titanium. Nevertheless, although all materials will probably benefit from the application of the rules, some will benefit almost out of recognition, whereas others will be less affected.

Listed in summary form, the rules are intended to assist the casting industry. Adhering to them will speed up the process of producing the casting right the first time, and should contribute greatly to reducing scrap when the casting goes into production. In this way, the casting industry will be able to raise standards without any significant increase in costs. Superior quality can be offered with confidence. Only in this way will castings be accepted by the engineering profession as reliable, engineered products, and assure the future prosperity of the casting industry and its customers.

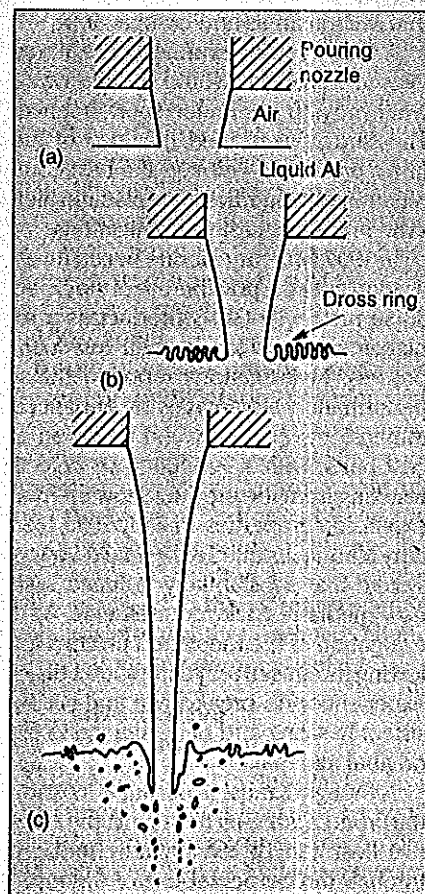
Conversely, the rules constitute a draft process specification, which buyers of castings could demand if they wished to be assured that they were buying the best possible casting quality. If buyers specified that their casting sources followed such rules, the quality and reliability of the castings would be higher than could be achieved by any amount



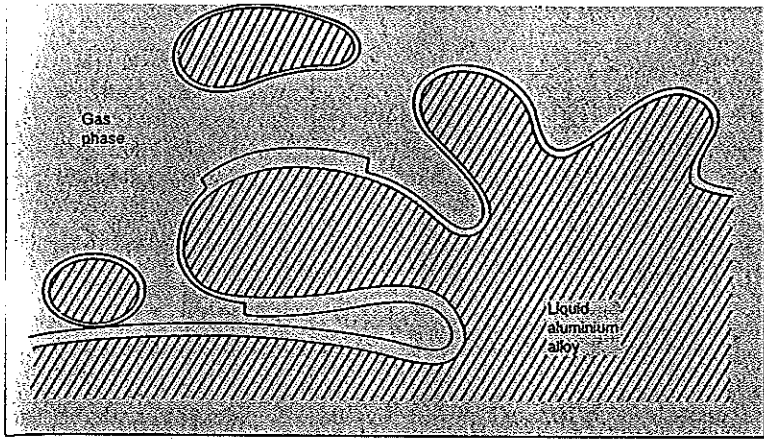
Rule 1. This figure shows the hydrogen solubility in aluminum and two of its alloys, illustrating the abrupt fall in solubility on solidification.



Rule 1. This chart shows mechanical property regimes for an Al-4.5Cu-1.5Mg alloy in filtered and unfiltered conditions [Hedjazi et al. (1975)].



Rule 2. These schematics show the effect of increasing height on a falling stream of liquid, illustrating: (a) the oxide film remaining intact; (b) the oxide film being detached and accumulating to form a dross ring; (c) the oxide film and air being entrained in the bulk melt.



Rule 2. This schematic view of a splash of molten aluminum shows the formation of a folded (double) film that might consist of thick old film, or new thin film, or both, all likely to occlude air in the folds.

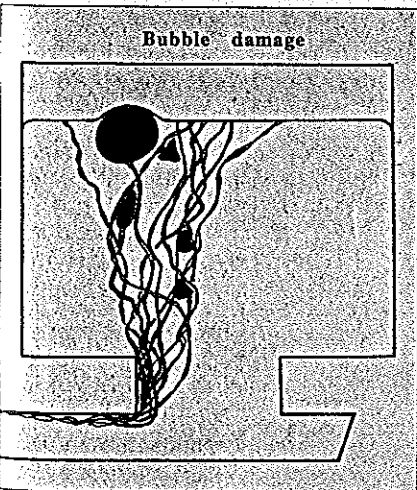
of expensive quality control on the finished product.

Rule 1. Provide a Good Quality Melt

Immediately prior to casting, the melt shall be prepared and treated if necessary using the best current practice. The aim is to provide a melt at the correct temperature, correct chemistry and with low residual levels of dissolved gas and inclusions. Inclusions, particularly oxide films, are reintroduced into the liquid metal by poor handling, such as pouring from furnaces and ladles prior to casting. Procedures to avoid such reintroduction of damage need to be introduced.

Rule 2. Avoid Liquid Front Damage

This is the requirement that the liquid metal front (the meniscus) should not go too fast. Maximum meniscus velocity is about 0.5 m/s. (This maximum velocity may be raised to 1 m/s in sections only a few mm thick.) However, surface turbulence damage



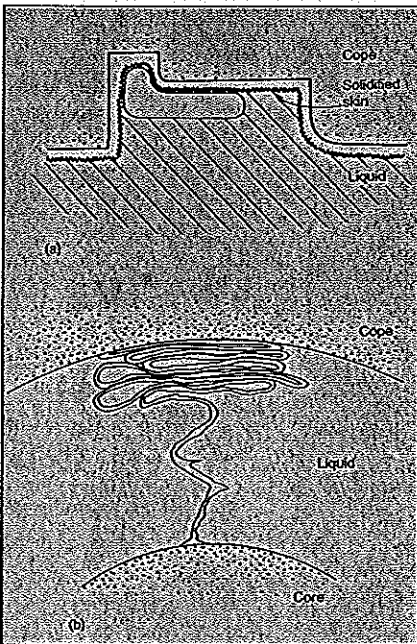
Rule 4. This drawing illustrates the most common defect in castings—bubble damage as a mixture of oxide cracks and residual entrapped bubbles.

can be avoided even at higher speeds if the casting filling system is sufficiently narrow to constrain the meniscus, not allowing room for splashing or droplet formation.

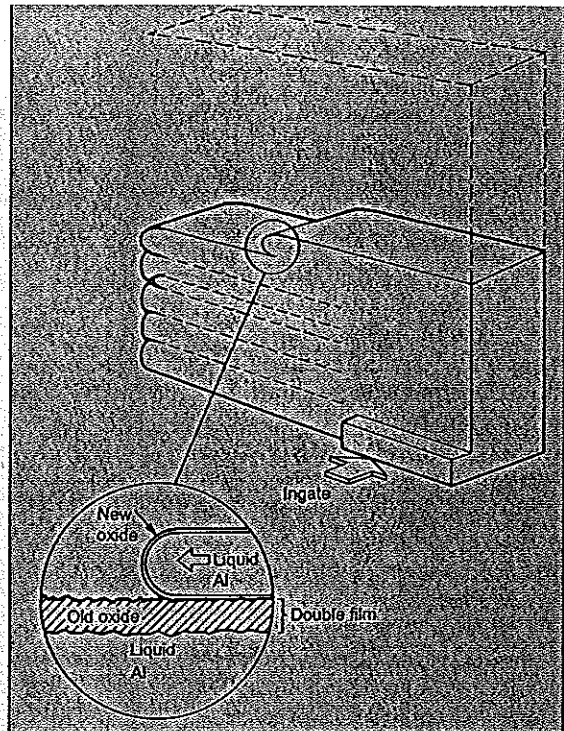
Rule 3. Avoid Arrest of the Liquid Front

This is the requirement that the liquid metal front should not go too slowly! And, more precisely, should not stop at any point on the front.

- The advancing liquid metal meniscus must be kept "alive" and free from thick oxide film that can be incorporated into the casting. This is achieved by ensuring that the liquid front only advance uphill (in the case of gravity



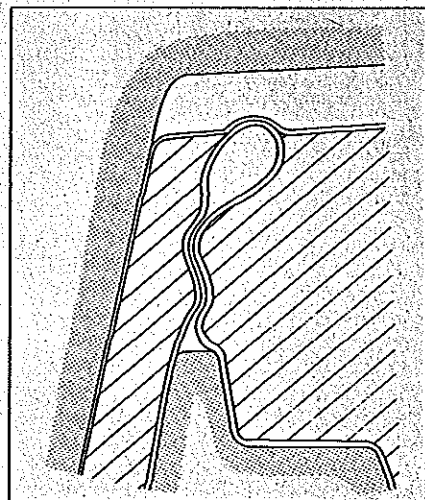
Rule 5. At top is a "core blow"—a trapped bubble containing core gases. Shown at the bottom is a bubble trail, ending in an exfoliated dross defect as the result of the passage of copious volumes of core gas. [After Frawley et al. (1974)].



Rule 3. This drawing shows the unstable advance of a film-forming alloy, showing the formation of laps as the interface intermittently stops and restarts by bursting through and flooding over the surface film.

poured casting processes, from the base of the sprue onwards). This implies that: only bottom gating is permissible, and no falling or sliding downhill of liquid metal is allowed.

- The meniscus must experience continuous uninterrupted upward advance. That is, no stopping due to arrest of pouring, and no extensive horizontal sections or waterfall effects (avoided by casting design or mold orientation), which will cause a general temporary arrest of the liquid front in the casting, and thus lead to oxide laps, or if prolonged, even cold laps.



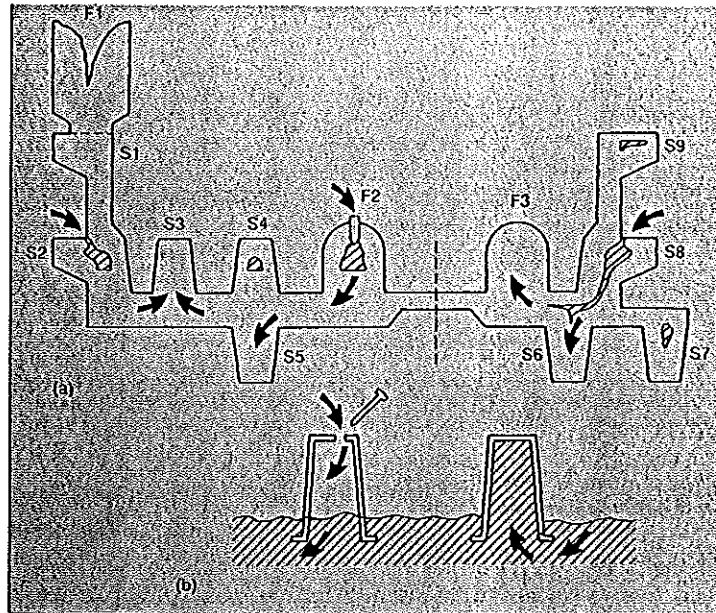
Rule 5. Illustrated here is the detachment of a bubble from the top of a core, bequeathing a bubble trail as a permanent legacy of its journey. This bubble may be early enough to escape at the free surface of the rising metal.



Rule 4. Avoid Bubble Damage

No air bubbles should be entrained by the running system. If they are entrained, then they should not be allowed to pass through the liquid metal in the mold cavity. If this happens, then a mixture of oxide bubble trails, together with residual misshapen bubbles in the casting, will result. This is by far the most common defect in castings, and is commonly mistaken for shrinkage porosity. This severe defect may be avoided by:

- Fast backfill of filling system by virtue of properly designed sprue and pouring basin, and use of a stopper in small castings, ceramic foam filters placed close to sprue/runner junction, and bubble traps. Any



Rule 6. This figure shows castings with blind risers. F2 is correctly vented, but has mixed results on sections S3 and S4. Riser F3 is not vented and therefore doesn't feed at all. The unfavorable pressure gradient draws liquid from a fortuitous skin puncture in section S8. The bottom drawing illustrates the plastic coffee cup analogue: the water is held up in the upturned cup and cannot be released until air is admitted via a puncture. The liquid it contains is then immediately released.

solutions must be demonstrated as effective using some suitable technique such as real-time X-ray radiography.

- No interruptions to pouring.



Rule 5. Avoid Core Blows

Gases from cores or even occasionally from parts of the mold should not be allowed to penetrate the liquid metal. Core or mold blows cause a rather different type of defect than the entrained air bubbles.

- Cores should be demonstrated to be of sufficiently low gas content and/or adequately vented to prevent bubbles from core blows. (This demonstration might be carried out by a video record-



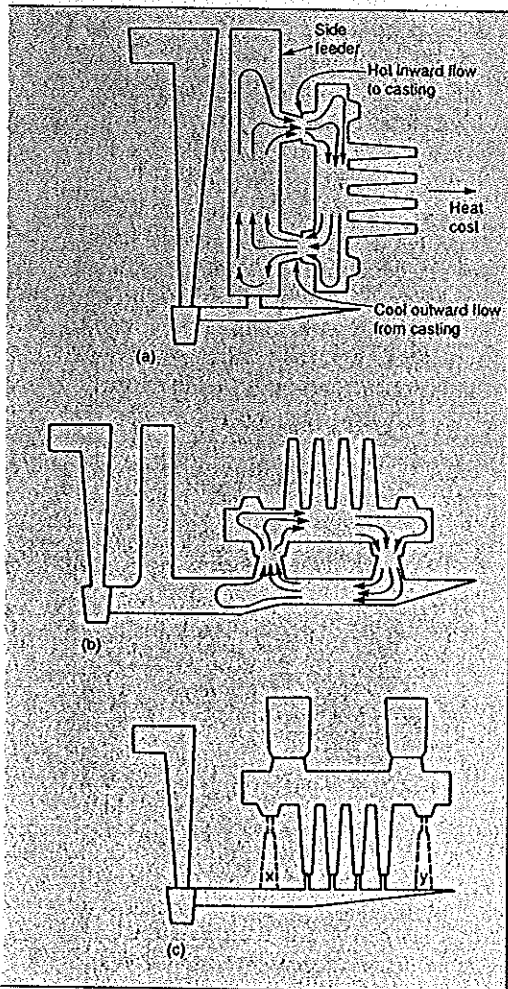
Rule 7. Avoid Convection Damage

Thin or thick section castings automatically avoid convection problems. Thin section castings freeze quickly before convection builds up. In thick section castings, convection helps redistribute hot metal into the risers on the top of the casting, since there is plenty of time before freezing starts.

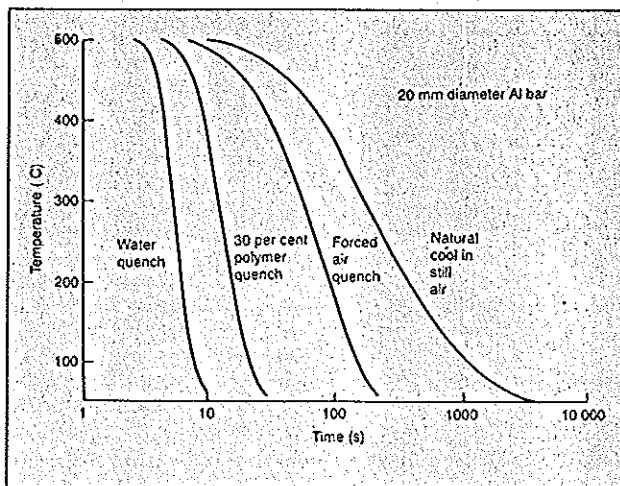
However, intermediate sections, which represent the great majority of castings, have a freezing time commensurate with the time taken for convection to operate (in a few minutes) and can cause damage.

Unsuitable temperature gradients in the casting can undermine the effectiveness of risers, and lead to segregation and apparent shrinkage damage in castings. This is a little-known and little-researched area that most current computersimulations cannot tackle. For such intermediate sections, either:

- Reduce the problem by avoiding convection loops in the geometry of the casting and rigging.
- Eliminate convec-



Rule 7. These illustrations show the encouragement of thermal convection by (a) side and (b) bottom feeding, and its elimination by (c) top feeding.



Rule 9. This chart shows the rates of cooling of a 20 mm diameter aluminum bar when quenched by various means from 932F (500C).

Rule 9. Elongation to Failure Results from Different Quenching Media

	Elongation (%) Mean ± 2.5	Minimum
Hot-water quench 158F (70C)	4.73 \pm 2.72	2.01
Cold-water quench	6.47 \pm 1.67	4.80
Water-glycol quench	5.81 \pm 0.96	4.85

tion by 180-degree roll-over after mold filling.

Rule 8. Plan Segregation Distribution

Change of section will normally involve change in distribution of alloying elements in the casting. This can mean parts of the casting are out of chemical specification. Such problems may need to be addressed if properties are threatened (such as a local brittleness, especially in a stressed region) and may require prior negotiation with the customer.

Rule 9. Control Residual Stress

Avoid unknown or random residual stress by forbidding quenching of low ductility, light alloy castings into water following high temperature solution treatment. Boiling water is also not permitted since it rep-

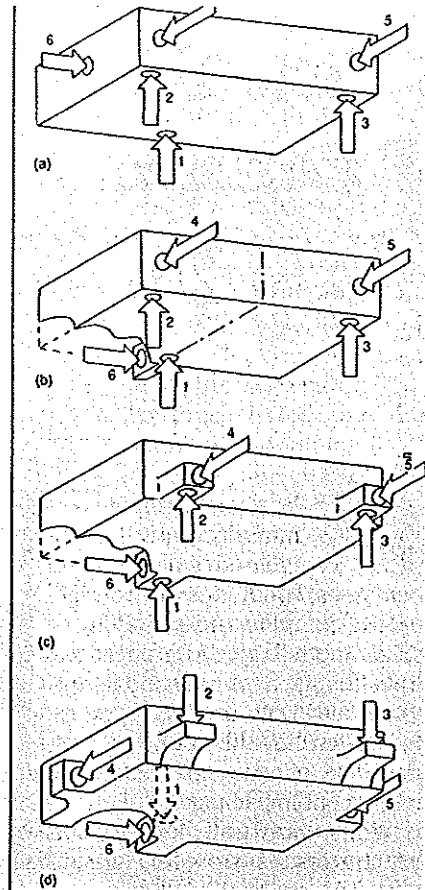
resents a negligible improvement over cold water. However, polymer quenchant or forced air-quench may be acceptable if casting stress is shown to be negligible. Planned residual stress may be beneficial if designed correctly into the quenching process.

Rule 10. Provide Location Points

All castings will be provided with agreed location points for dimensional reference and for pickup for machining. The combination of clamping points to be used during machining is also usually helpful and easily incorporated, as illustrated in Fig. 10a.

Illustrations were excerpted from Campbell's book, Castings, published by Butterworth-Heinemann, Ltd. It is available from AFS Publications at 800/537-4237.

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Rule 10. These drawings show ways in which the six-point location method can be used on a casting.

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