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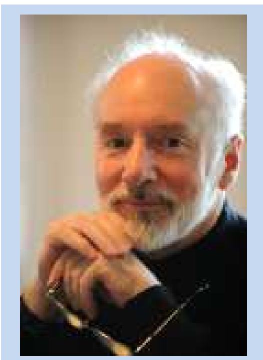

Professor Dr. John Campbell's Ten Rules for Making Reliable Castings

Dr. John Campbell
FRSH, OBE

OBE (born 1938) is a British engineer and one of the world's leading experts in the casting industry with approximately 150 papers, and 20 patents. Campbell holds two Masters degrees from University of Cambridge and University of Sheffield, as well as two doctorates from University of Birmingham. He is a fellow of the Royal Academy of Engineering, and he was appointed to the chair of casting technology at University of Birmingham. The Institute of Cast Metals Engineers has named the "John Campbell Medal" after him.

John Campbell is a leading international figure in the castings industry, with over four decades of experience. He is the originator of the Cosworth Casting Process, the pre-eminent production process for automobile cylinder heads and blocks. He is also co-inventor of both the Baxi Casting Process (now owned by Alcoa) developed in the UK, and the newly emerging Alotech Casting Process in the USA. He is Professor Emeritus of Casting Technology at the University of Birmingham, England, UK.

The Ten Rules listed here are proposed as necessary, but not, of course, sufficient, for the manufacture of reliable castings. It is proposed that they are used in addition to existing necessary technical specifications such as alloy type, strength, and traceability via international standard quality systems, and other well-known and well-understood foundry controls such as casting temperature etc.

Although not yet tested on all cast materials, these are fundamental reasons for believing that the Rules have general validity. They have been applied to many different alloy systems including aluminium, zinc, magnesium, cast irons, steels, air- and vacuum-cast nickel and cobalt and even those based on highly reactive metals titanium and zirconium. Nevertheless, of course, although all materials will probably benefit almost out of recognition, whereas others will be less affected.

The Rules as they stand therefore constitute a first daft of a Process Specification, more like a checklist of casting guidelines. A buyer of castings would demand that the list was fulfilled if he wished to be assured that he was buying the best possible casting quality. If he were to specify the adherence to these Rules by the casting producer, he would ensure that the quality and reliability of the castings was higher than could be achieved by any amount of expensive checking of the quality of the finished product.

Conversely, of course, the Rules are intended to assist the casting manufacturer. It will speed up the process of producing the casting right first time, and should contribute in a major way to the reduction of scrap when the casting goes into production. In this way, the caster will be able to raise the standards, without any significant increase in costs. Quality will be raised to a point at which castings of quality equal to that of forgings can be offered with confidence. Only in this way will castings be accepted by engineering profession as reliable, engineered products, and assure the future prosperity of both the casting industry and its customers.

For a successful casting operation, one of the revered commercial goals is the attainment of product sales being at least to manufacturing costs. There are numerous other requirements for the successful business, like management, plant and equipment, maintenance, accounting, marketing, negotiation, managing competitive position, and profitability. All have to be adequate, otherwise the business can suffer, and even fail.

Without good castings it is not easy to see what future a casting operation can have. The production of good castings can be highly economical and rewarding. The production of bad castings is usually expensive and damaging. The "good casting" is defined as one that meets or exceeds the customer's specification. It is also worth noting at this early stage, that we hope that meeting the customer's specification will be equivalent to meeting or exceeding service requirements. However, occasionally it is necessary to live with the irony that the aims of the customer and the requirements of service are sometimes not in harmony one would like to see.

These problems illustrate that there are easier ways of earning a living than in the casting industry. But few are as exciting.

John Campbell, West Malvern. 3 September 2003

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The 10 Rules are my personal checklist (Campbell, 2004), ensuring that I have not forgotten any essential aspect of casting manufacture. Nevertheless, it cannot be emphasized that the failure of only one of the rules can result in total failure of the casting. This is not meant to be alarmist, but simply practical. No one has ever promised that making castings would be easy. However, following the rules is a great help.

Rule 1 Start with a good melt

Immediately before casting, the melt shall be prepared, checked, and treated, if necessary, to bring it into conformance with an acceptable minimum standard. Prepare and use so far as possible only near-defect-free melt. A good quality liquid metal is one that is defined as follows:

Substantially free from suspensions of non-metallic inclusions in generals and bi-films in particular
Relative freedom from bi-film straightening and bi-film opening agents. These include certain alloy impurities in solution such as Fe in Al alloys and hydrogen or other gases. However, it should be noted that Si can precipitate in its primary form as a bi-film straightening element and is, of course, inescapable when using modified Al-Si alloys, but is avoided in modified alloys.

Rule 2 Avoid turbulent entrainment of the surface film on the liquid

This is the requirement that the liquid metal front (the meniscus) should not go too fast. Maximum meniscus velocity is approximately 0.5 m/s for most liquid metals. This requirement also implies that the liquid metal must not be allowed to fall more than the critical height corresponding to the height of a sessile drop of the liquid metal. The maximum velocity many be raised to 1.0 m/s or even higher, and the critical fall height might be correspondingly raised to 50 mm, in sufficiently constrained running systems or thin section castings.

Rule 3 Avoid laminar entrainment of the surface film on the liquid

This is the requirement that no part of the liquid metal front should come to a stop before the complete filling of the mould cavity. The advancing liquid metal meniscus must be kept "alive" (i.e. moving) and therefore free from thickened surface film that may be incorporated into the casting. This is achieved by the liquid front being designed to expand continuously. In practice, this means progress only **uphill** in a continuous **uninterrupted** upward advance (i.e. in the case of gravity-poured casting process, from the base of the sprue onwards). This implies

- Only bottom-gating is permissible
- No falling or sliding downhill of liquid metal is allowed
- No horizontal flow of significant extent
- No stopping of the advance of the front due to arrest of pouring or waterfall effects, etc.

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Rule 4 Avoid bubble damage

No bubbles of air entrainment by the filling system should pass through the liquid metal in the mould cavity. This may be achieved by:

- Properly designed off-set step pouring basin; fast back-fill of properly designed sprue; preferred use of stopper;
  Avoidance of the use of wells and all other volume-increasing features of filling systems (such as expanding channels sometimes known as 'diffusers'); small volume runner and/ or use of ceramic filter close to sprue/runner junction; possible use of bubble traps. A naturally pressurised filling system fulfills most of these criteria.
- No interruption in pouring

Rule 5 Avoid core blows

- No bubbles from outgassing of cores or moulds should pass through the liquid metal in the mould cavity. Cores to be demonstrated to be sufficiently of low gas content and/ or adequately vented to prevent bubbles from core blows.
- No use of impermeable clay-based core or mould repair paste.

Rule 6 Avoid shrinkage

- No feeding uphill in larger section thickness castings. Feeding against gravity is unreliable because of (1) adverse pressure gradient and (2) complications introduced by convection.
- Demonstrate good feeding design by following all seven Feeding Rules, by an approved computer solidification model, and by test castings.
- Once good feeding is attained, fix the temperature regime by controlling (1) the level of flash at mould and core joints, (2) mould coat thickness (if any), and (3) temperatures of metal and mould.

Rule 7 Avoid convection

Avoid the freezing time in relation to the time for convection to cause damage. Thin- and thick- section castings automatically avoid convection problems. For intermediate sections, either (1) reduce the problem by avoiding convective loops in the geometry of the casting and feeding/gating system, (2) avoid feeding uphill, or (3) eliminate convection by rollover after filling.

Rule 8 Reduce segregation

Predict segregation to be within limits of the specification, or agree out-of-specification compositional regions with customer. Avoid channel segregation formation if possible.

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Rule 9 Reduce residual stress

No quenching into water (cold or hot) following solution treatment of light alloys. Polymer quenchant or forced air quench may be acceptable if casting stress can be shown to be acceptable.

Rule 10 Provide location points

All castings to be provided with location points for pickup for dimensional checking and machining. Proposals are to be agreed on with quality auditor, machinist, and other concerned departments