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# CONSIDERATIONS ON THE CASTABILITY OF METALLIC MATERIALS USED FOR THE REALISING OF SMALL-SIZE PARTS

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## ABSTRACT
*The paper intends to study the advantages and shortcomings of the methods currently used for the assessment of castability in the case of small-size parts. Furthermore, the authors propose some new methods that offer a series of advantages as compared to those currently in use. They are based on various shapes of rods cast from the tested materials and can be used under different conditions required by the shapes of actual parts that are to be realised.*
**Keywords:** castability, test pattern, small-size cast parts

## 1. INTRODUCTION
Currently, the range of commercially available metallic alloys used for the realising of cast parts is very wide, Taking only the example of small-size parts used for the manufacturing of prosthetic elements, there are some 800 different metallic materials available [2]. The high diversity of these materials can pose problems to both the technical personnel processing these parts, but also to the end users, e.g. to patients in need of prostheses. Processing companies must continuously adapt their auxiliary materials, their technologies and often even the laboratory equipment in order to meet the technological demands of newly emerging materials.
For example, titanium has become in the past years a true "star material" in industry applications but also in medicine, both as stand-alone metal and in various alloys, because it offers a series of clear advantages compared to other, "classical", metals: it is lightweight, is absolutely biocompatible, has an excellent corrosion resistance, a low heat conductivity etc. However, titanium has also a very high melting point and a high chemical reactivity, which makes its casting very difficult, requiring special laboratory equipment. Assessing the quality behaviour of cast parts made of titanium or titanium alloys is therefore very important.
Also, when dealing with small size parts, we are dealing with high-precision casting technologies, very demanding in their execution, as often parts have wall thicknesses of the order of tenths of millimetres and in some cases the allowable dimensional errors must be limited to ±0,05...±0,1 mm.
The causes for the failure of such casting processes and the failure types are very numerous, and they demand the full attention and experience of the specialists, as well as the usage of high-end techniques and equipment. It is therefore important to analyse the casting operations and the obtained parts also from a qualitative point of view, taking into account the materials used and the accuracy of the employed technologies.

## 2. CASTABILITY AND CASTABILITY ASSESSMENT METHODS
The notion "quality of cast parts", which is related to the presence or absence in the cast parts of defects such as pores, shrinkage holes etc. is strongly related to the notion of "castability" of the material of which the parts are made. The latter can refer to both the completeness of the casting, in the sense of the cast part proportion which could be correctly reproduced during the casting process, and to the casting precision, i.e. to the minimal dimensions of the details which could be reproduced.

The casting process and the castability of materials can be influenced by a wide range of factors and therefore it is very difficult to find a single definition to cover all aspects of this notion, or to define a dimension of the castability.
Various authors [3, 4] have tried to determine a castability value by means of theoretical calculations. However, in order to keep these calculations in a reasonable range of complexity, they take into account only a part of the factors and neglect others.
The most-used practical castability assessment methods are related to the usage of test patterns with special shapes and sizes. Such test patterns are flat or spatial mesh patterns (fig. 1 a), flat or spatial coil patterns, the saucer (disc) pattern (fig. 1 b), the wedge patterns (fig. 1 c) etc.

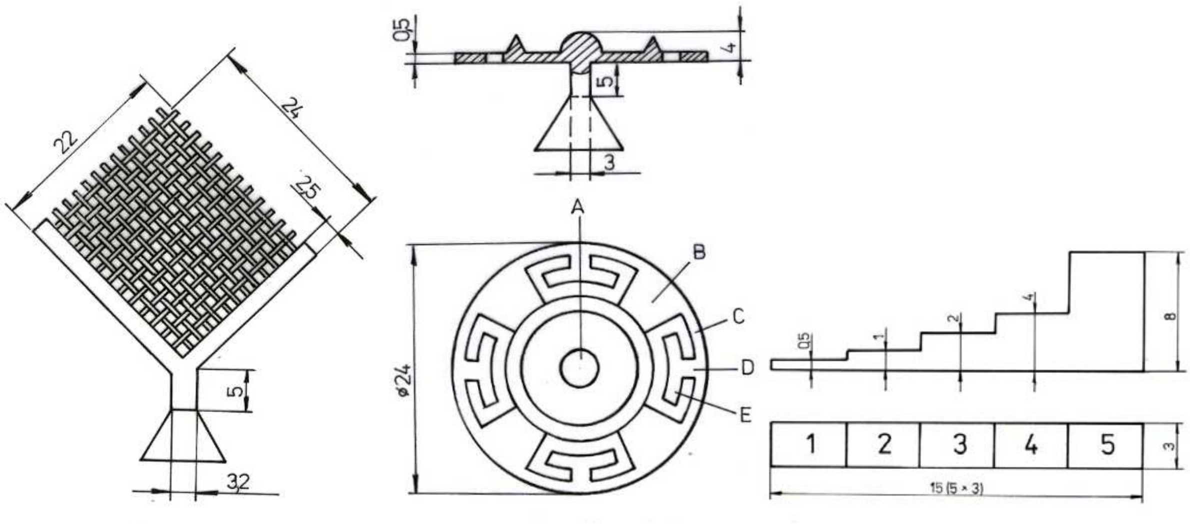


*Figure 1. Test patterns currently used for the assessment of castability*
*a) flat mesh pattern; b) saucer pattern; c) wedge pattern*

The methods and casting patterns which are currently in use attempt to provide the specialists with information regarding the castability of metallic materials. However, with all their diversity, the information provided by these methods are relatively limited, or have a much too particular character.
The methods used for assessing the castability should focus on offering the most important data, related to both the influence of the size of the runner cross-section, and the changes of direction in the flow of the molten metal, on the obtained part, for a specific casting procedure. It is also useful to express the castability as precise as possible, based on widely-accepted criteria or measurement units.
The saucer pattern, for example, offers only information limited by the fixed pattern diameter, by the fixed thicknesses of the pattern's cross-section and mainly by the relatively short distance which the molten material must go through. Thus, the assessment of castability with this method becomes subjective, not least because of the equal importance granted to the completeness of the various cross-sections found on the test patterns. Similar critiques can be brought also against the other types of test patterns.
A direct consequence of these limitations is the fact that, currently, there exists no casting pattern that would be easy to manufacture, simple to use and that would offer complete information on the casting behaviour of a certain metallic material. Furthermore, a good castability assessment method should allow an easy manufacturing of the pattern associated with it, an easy adaptation to the various shapes and wall thicknesses encountered in practice and the collecting of a maximal amount of data with the help of a minimal number of cast patterns.
Table 1 shows a comparative analysis of the most important methods which are currently used for the assessment of the castability of metallic alloys used for the manufacturing of small-size dental prosthetic parts.
Several criteria were taken into account for this analysis:

- A - the amount of information regarding the influence of the various cross-sections and lengths of the test pattern;
- B - the amount of information on the influence of direction changes in the flow of the molten material;

- C – the objectivity of the castability assessment (the capability to express the castability in measurable units instead of by "eye-weighing");
- D – the ease of manufacturing the test pattern;
- E – the capability of adapting the test pattern to other cross-section thicknesses or other dimensions;
- F – the capability of offering simultaneous information on several cross-section thichnesses and part sizes, including non-standard ones.

*Table 1. Efficiency of the usage of various test patterns for castability assessment*

| Test pattern type | Points awarded (1...10) for the criterion | | | | | | Total number of points | Overall efficiency rank |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | | |
| Saucer (disc) pattern | 8 | 10 | 8 | 9 | 0 | 0 | 35 | 2 |
| Wedge pattern | 7 | 0 | 8 | 9 | 7 | 0 | 31 | 5 |
| Flat mesh pattern | 6 | 9 | 7 | 4 | 4 | 0 | 30 | 6 |
| Spatial mesh pattern | 6 | 10 | 7 | 2 | 4 | 0 | 29 | 7 |
| Flat coil pattern | 5 | 6 | 6 | 7 | 10 | 0 | 34 | 3 |
| Spatial coil pattern | 5 | 10 | 6 | 2 | 10 | 0 | 33 | 4 |
| D pattern (new) | 9 | 8 | 8 | 4 | 10 | 8 | 47 | 1 |

The degree of fulfilment of each criterion by the various test patterns has been noted with a score from 1 to 10, and a ranking of the methods was established.

## 3. A NEW TEST PATTERN FOR THE ASSESSMENT OF CASTABILITY

As a result of the analysis of the advantages and disadvantages displayed by the test patterns which are currently the most widely used in practice for the assessment of the castability, the authors have elaborated two new assessment methods, based on new types of test pattern.
A first test pattern developed by the authors, the "sinus runner pattern", consisted of a runner of circular cross-section bent along sinusoidal curves at certain intervals. This pattern type eliminates many of the disadvantages seen with other pattern types. However, it would still fail the criterion F, as it could offer information only about one specific material thickness at a time.
Therefore. the authors developed a more complex pattern, designated the "D pattern". It consists of several "sinus runner patterns" connected in parallel, each runner or "branch" having another diameter. Figures 2 and 3, for example, show the design specifications and the practical realisation for a pattern with 3 branches of different diameters.
The casting cone which is formed at the casting of the pattern can be preserved as part of the pattern, as it facilitates its manipulation.
As table 1 shows, the D pattern has the highest overall efficiency ranking, presenting several advantages compared to the other types of test patterns which are currently in use, advantages which are reflected in the scores awarded for the behaviour of this pattern in relation to the criteria taken into account.
Among these advantages it is worth mentioning the possibility to simultaneously (by means of one single casting operation) offer information on the behaviour of the tested metallic material during its flow (in molten state) through long runners with various cross-section sizes and with several changes of direction, the capability of adapting the "D pattern" to virtually any cross-section size or wall thickness and, not least, the ease of manufacturing this type of pattern.
As a practical example of using the new method, figure 2 shows a D pattern which was cast from a Ni-Cr-based alloy, Wirolloy (63.2 % Ni, 23.0 % Cr, 9.0% Fe, 3.0 % Mo, 1.8 % Si, <0.1 % C), with runners of diameters Ø2.5, Ø2 and Ø 1.5 mm, respectively.
The castability of metallic alloys in the context of this pattern could be assessed by means of the castability coefficient $C_{t,di}$ (for the diameter $d_i$ of the $i$ branch of the test pattern):

$$C_{t,di} = (5 - d_i) \cdot 5 + (20 - m_i) + 2n_i, \qquad (1)$$

where $d_i$ and $m_i$ represent the dimensions as indicated in figure 2;
$n_i$ represents the number of completely cast "$s_i$" distances resulted on the cast pattern.

For example, for the case of the test pattern presented in figure 3:

$C_{t,2,5} = (5-2.5)\cdot5 + (20-18) + 2\cdot5 = 24,5$

$C_{t,2} \ = (5-2)\cdot5 + (20-18) + 2\cdot5 = 27$

$C_{t,1,5} = (5-1.5)\cdot5 + (20-18) + 2\cdot5 = 29,5.$

These values indicate a high castability of the Wirolloy alloy, so this material is suitable for the casting of parts with even very fine details.

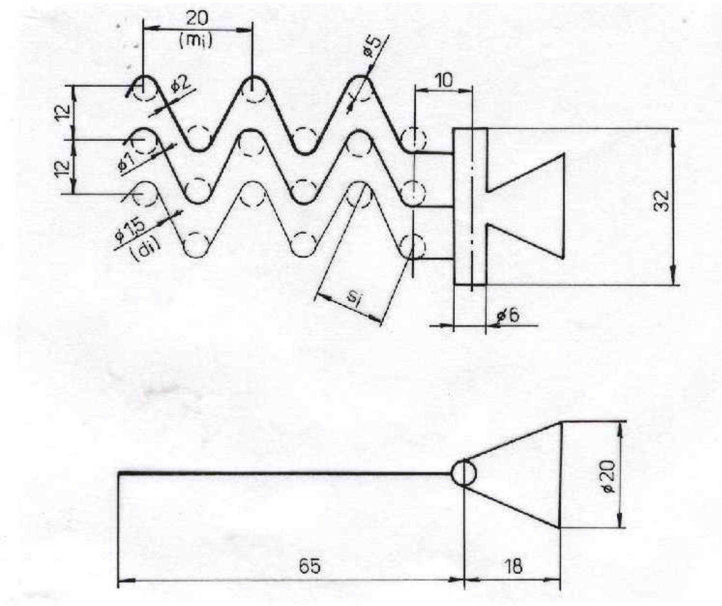


*Figure 2. The newly elaborated test pattern "D"*

*Figure 3. D pattern cast from Wirolloy alloy, with the diameters of the branches of 2.5, 2 and 1.5 mm*

## 4. CONCLUSIONS

The assessment of the quality of small-size cast parts, together with the assessment of the castability of metallic casting materials, should occupy an important place in the preoccupations of any research institution or laboratory from this field of activity.

The various theoretical or practical methods which are currently used for the assessment of the castability, cannot characterise this property by taking into account all factors involved.

Therefore, new methods, based on the usage of new types of test patterns, have been developed and tested in practice, one of them with good results.

The new "D pattern" offers several advantages over the classical patterns, such as the possibility of assessing the capability of a metal to enter and fill out in its molten state thin and/or long segments of a casting mould by means of one single casting operation and the capability to adapt the pattern to different cross-sections as needed. Furthermore, the new test pattern is easy to manufacture and use.

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