Development of Quality Index For Cast Aluminium-7 Silicon-Magnesium Alloys

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Abstract: An assessment of the possibility of development of the Quality Index $Q = T + 150 \log E$ using recently derived data of good reliability on Al-7Si-Mg alloys was made and a number of limitations of the Drouzy's approach was found. An alternative definition of Quality Index $Q = P - k.E$ seems useful and appropriate. This new definition may have wider applicability, but requires to be further investigated. The use of P versus E maps is recommended to encompass the whole range of properties of interest to the designer.

Keywords : *Quality Index, A356, A357.*

INTRODUCTION

Irrespective of the type of metal from which a casting is made, it is normally essential that its mechanical properties should be known. In fact, the selection of a particular alloy is usually made primarily on the knowledge that certain mechanical properties can be developed in castings made from the alloy, and secondly on other factors such as density, corrosion resistance, cost etc.

Although the mechanical property data used for the selection of a particular alloy is similar in form for the multitude of ferrous and non-ferrous alloys available, the methods of assessing the data show wide variations. In addition to assessing data for materials selection, the obtaining of mechanical property values gives ongoing information with regard to the quality control aspects in commercial foundries. A third use for mechanical property determination is in foundry development, where the results are taken as an indication of the effects of deliberate changes in whatever process variables are being studied.

Presently, the mechanical properties of a given material are reported in the form of ultimate strength, proof strength, elongation and hardness. In a practical situation, one can achieve only two of these required properties, and it is often difficult to satisfy three or more. This is because, in practice, all the property values which are chosen for the specification are to some extent mutually inconsistent - the designer has specified high 0.2% proof strength but the machinist requires low hardness to aid machinability, whilst the safety engineer has specified high elongation to avoid brittle failure. So the general trend nowadays is to report the tensile data in the form of ultimate strength and total percentage of elongation at failure.

Although an investigation concerning the methods of assessing the mechanical properties of all commercial foundry alloys would be interesting, this investigation was concerned with aluminium alloys, in particular the Al-7Si-Mg alloys (A356 and A357 series). This is an already widely used high-strength aerospace casting alloy, and seems to be becoming more important for complex shaped parts which are required to have good structural integrity. Its relatively straightforward precipitation hardening reaction involving the precipitation Mg_2Si makes it an ideal research material.

Alloy	Al	Si	Mg	Fe	Cu	Mn	Zn	Ti
A356	Rem.	7.04	0.39	0.32	0.03	0.23	0.03	0.03
A357	Rem.	6.98	0.53	0.34	0.06	0.28	0.06	0.04

THE QUALITY INDEX

The ability to denote the quality of a cast alloy by a single number was the inspired innovation of Drouzy and his co-workers [1]. They defined the Quality Index Q as

$$Q = T + 150 \log E \qquad (1)$$

where Q is measured in MPa, ultimate tensile strength T is in MPa, and elongation E is in %. The factor 150 is an empirically determined constant applicable to alloys in the A356 and A357 system. It reflects the fact observed by the French workers that as a particular batch of cast alloy is subjected to normal ageing treatment a graph of TS versus log E is a straight line of slope close to 150 MPa/% elongation. If steps are taken to improve the quality of the melt by, for instance, reducing porosity, then a new parallel line is formed at higher levels of strength and/or ductility. The expression for quality index is, however, valid only for $E \geq 1\%$.

Drouzy and co-workers used the T-E diagram, with the help of the quality index and another quantity, the probable proof strength P^o, defined [1] by the equation $P^o = T - 60 \log E - 13$ for the diagnosis of a possible problem with the mechanical tensile characteristics of castings. Conversely, they also used the concept for the prediction of tensile strength and elongation. The readers are strongly encouraged to go through the Drouzy's approach of interpreting tensile data [2].

METHOD

Research works [3,4,5] have been carried out to test the Quality Index concept using recently derived data of good reliability on Al-7Si-Mg casting alloys.

As a general technique for the plotting of data, it was found helpful to plot the as-cast and the underaged results up to peak ageing as solid symbols, and overaged data as open symbols. In this way it was possible to identify the source of data in the regions of overlap.

DEVELOPMENT OF A NEW QUALITY INDEX

From the works, it is clear that, apart from the limitations that the castings only with an elongation value greater than or equal to one per cent shall be eligibe to be evaluated, the Drouzy's Quality Index has some serious drawbacks:

(1) From the stress-strain relationship, it is clear that the ultimate tensile strength and the total percentage of elongation are interrelated. Above the yield point (corresponding approximately to the 0.2% proof strength) the more a test specimen extends plastically before fracture, the higher the final stress climbs because of the work hardening of the alloy. So in the Drouzy's equation $Q=T+150\log E$, the two parameters, T and E, are not entirely independent, so that a degree of double counting appears to be introduced.

(2) Using the data, the graphs of T versus log(% Elongation) were created in Figures 1 and 2. The extensive range of the data, including as-cast, solution treated (i.e. zero hours aged), and highly overaged conditions represents a severe test of the concept. A line of slope 150 has been superimposed on the data. Clearly the data are not well described by the existing Quality Index.

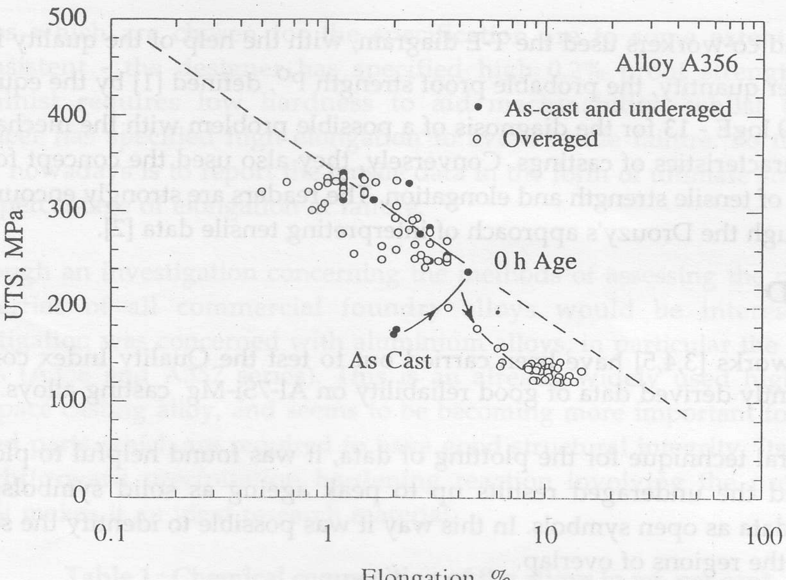
500
400
300
200
100
0
UTS, MPa
0.1
1
10
100
Elongation, %
Alloy A356
As-cast and underaged
Overaged
0 h Age
As Cast

Fig. 1 : T versus log%E map for sand cast A356 alloy with a superimpose line of slope 150 MPa/%.

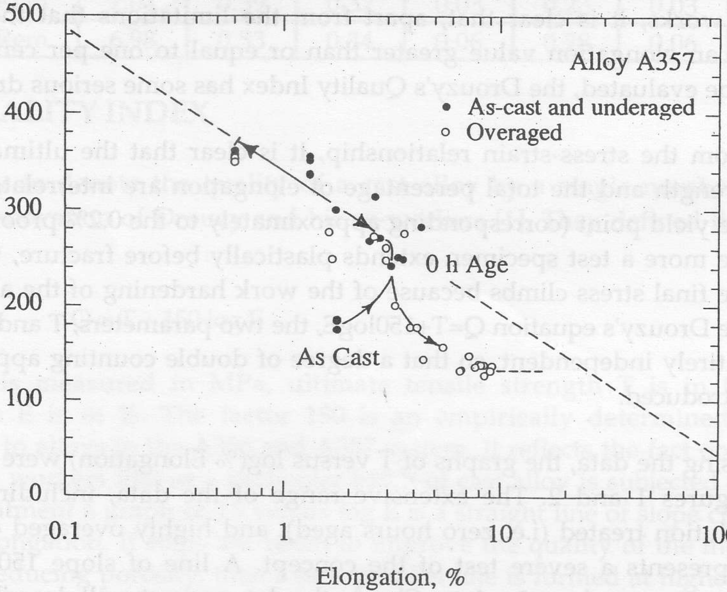

Fig. 2 : T versus log%E map for sand cast A357 alloy with a superimpose line of slope 150 MPa/%.

(3) The proposal that the Quality Index should be independent of heat treatment and other hardening parameters is seemed to be fit only for the as-cast materials. So, castings that underwent subsequent heat treatment and other hardening operations are simply unsuitable to be assessed. It has been found [3,6] that the quality of sand casting decreases during over-ageing, and the high quality of chill casting improves further by over-ageing, contrary to normal expectations. Drouzy's Quality Index apparently failed to reflect this valuable increment of elongation when gravity die cast materials are over-aged. Furthermore, the magnesium content is shown to increase the quality line, hence the Quality Index of the alloy.

(4) Other heat treatment parameters, for example, the temperature and time of solution treatment and artificial ageing probably also have an influence over the Quality Index. In fact, Drouzy himself had found that an improved solution treatment will raise the Quality Index. Also, he had not fully investigated the over-aged condition, where his Index definitely varies from the values found for the under-aged condition.

As an exploration of the concept of Quality Index, Figures 3 and 4 were made. Ultimate tensile strength has now been abandoned for yield strength, closely

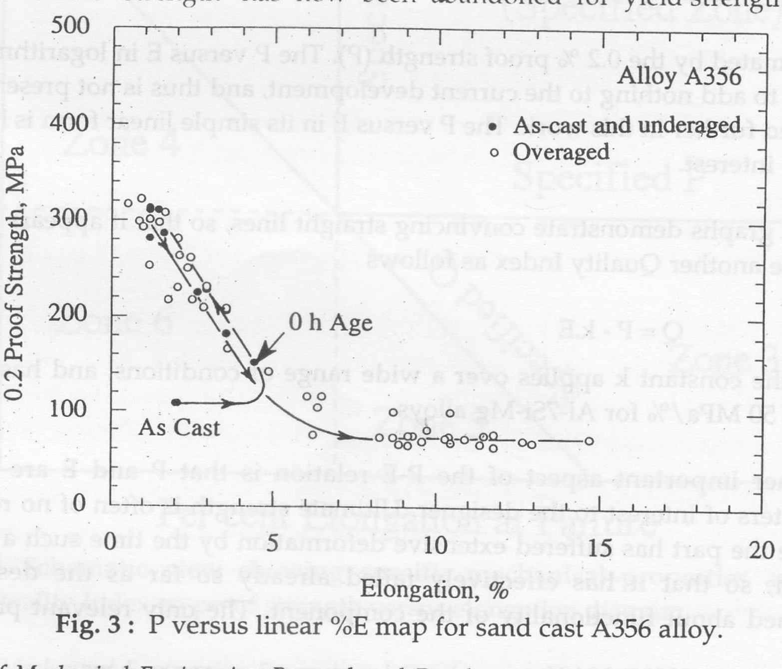

Fig. 3 : P versus linear %E map for sand cast A356 alloy.

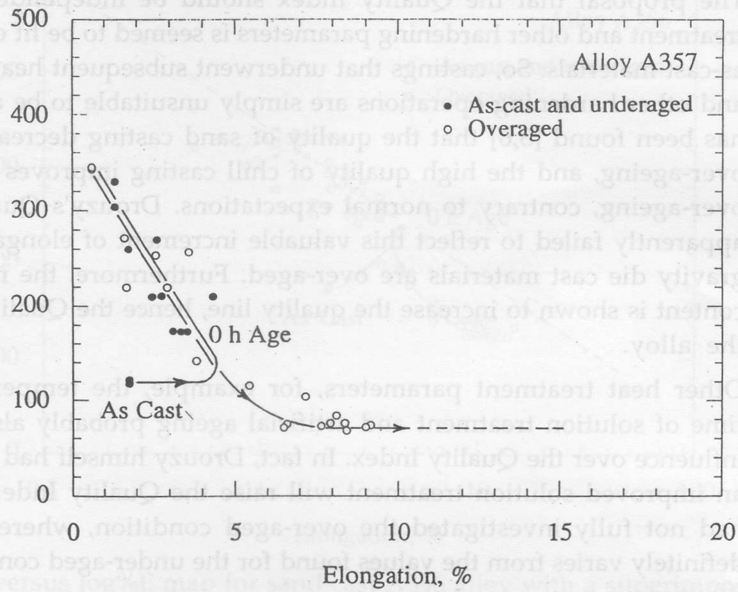

Fig. 4 : P versus linear %E map for sand cast A357 alloy.

approximated by the 0.2 % proof strength (P). The P versus E in logarithmic form appears to add nothing to the current development, and thus is not presented nor discussed further in this work. The P versus E in its simple linear form is however of great interest.

The P-E graphs demonstrate convincing straight lines, so that it appears possible to define another Quality Index as follows

$$Q = P - k.E \qquad (2)$$

where the constant k applies over a wide range of conditions, and has a value close to 50 MPa/% for Al-7Si-Mg alloys.

A further important aspect of the P-E relation is that P and E are the two parameters of interest to the designer. Ultimate strength is often of no relevance because the part has suffered extensive deformation by the time such a stress is reached, so that it has effectively failed already so far as the designer is concerned about functionality of the component. The only relevant parameter regarding strength is P. Clearly the 0.2% proof strength is intended to give information about the yielding behaviour of a material, and is measured by considering only a very small amount of permanent or plastic deformation. So to a fair approximation the proof strength can be considered as independent of the total percent of elongation which is a measure of the total plastic deformation to failure. The value of E, on the other hand, is an interesting safety factor which offers reassurance to the designer.

INTERPRETATION OF TENSILE RESULTS

In this section the interpretation of tensile results using the proposed Quality Index will be discussed, keeping in mind the method of interpretation used by Drouzy and others [2] using their proposed Quality Index.

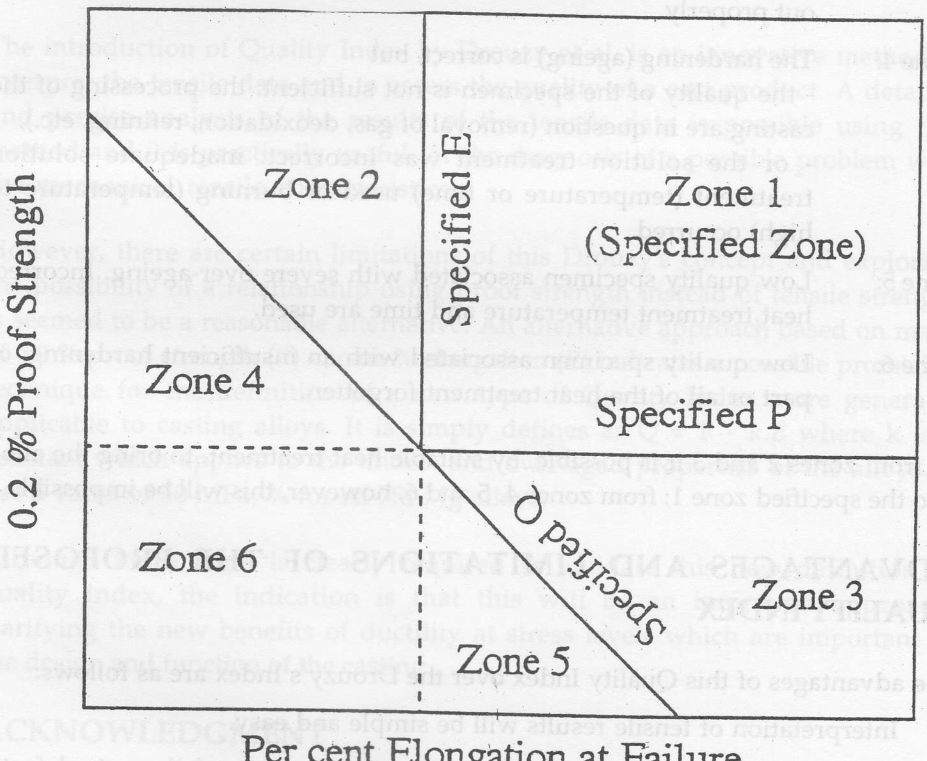

Fig. 5: A Schematic view showing specific mechanical properties and the Quality Index on proof strength versus elongation diagram.

On a P-E diagram (Figure 5) the minimum specific values of elongation, the proof strength, and the Quality Index are shown. Thus six zones are defined on the diagram. It is possible then to specify the different causes of lack of characteristics corresponding to the zones on the diagram.

Zone 1: Correct characteristics.

Zone 2: The quality of the unrefined specimen is good, but the alloy has become too hard. By reducing the temperature or the time of normal ageing it is possible to meet the specification.

Zone 3: The quality of the unrefined specimen is good, but the alloy has not been harden enough. Probably the temperature or the time of ageing was not enough (too high a temperature or too long a time also lead to a softening of the alloy). The quenching may not have been carried out properly.

Zone 4: The hardening (ageing) is correct, but
- the quality of the specimen is not sufficient: the processing of the casting are in question (removal of gas, deoxidation, refining, etc.),
- or the solution treatment was incorrect: inadequate solution treatment (temperature or time) used or burning (temperature to high) occurred.

Zone 5: Low quality specimen associated with severe over-ageing. Incorrect heat treatment temperature and time are used.

Zone 6: Low quality specimen associated with an insufficient hardening; or part or all of the heat treatment forgotten.

So from zones 2 and 3 it is possible, by suitable heat treatment, to bring the alloy into the specified zone 1; from zones 4, 5 and 6, however, this will be impossible.

ADVANTAGES AND LIMITATIONS OF THE PROPOSED QUALITY INDEX

The advantages of this Quality Index over the Drouzy's Index are as follows:

1. Interpretation of tensile results will be simple and easy.
2. The result will be more accurate and representative of the actual facts. Because nowadays the designers are interested only on the proof strength, not the tensile strength.

3. The equation is not confined to a value of elongation E ≥1% and thus appears to be a more generalised one than the Drouzy's equation.
4. Quality Index was found to vary with the ageing condition and the magnesium content. Also, the remarkable phenomenon that is found in chill casting that over-ageing improves ductility and proof stress of the alloy can also be truly reflected using this method [3,6].

The introduction of proof strength in the proposed quality equation makes it little bit difficult to calculate a Quality Index for a cast material as compared to Drouzy's method because of the fact that, in a tensile test, the tensile strength data is easier to obtain than the proof strength.

CONCLUSION

The introduction of Quality Index by Drouzy et al. is an innovative method to interpret the tensile data and to assess the quality of a cast product. A detailed and precise analysis of the results of the tensile data is possible using this method and it is practically useful for the diagnosis of a possible problem with the mechanical tensile characteristics.

However, there are certain limitations of this Drouzy's concept and exploring the possibility of a relationship using proof strength instead of tensile strength is seemed to be a reasonable alternative. An alternative approach based on maps of 0.2 % proof strength (P) versus % elongation (E) indicates a possible promising technique for the definition of a new type of Quality Index more generally applicable to casting alloys. It is simply defines as Q = P - k.E where k is a constant which applies to the under- and over-aged properties of the alloys. It has a value of 50 MPa/% for Al-7Si-Mg alloys.

Although more work is clearly required to validate this new definition of quality index, the indication is that this will be an improved approach, clarifying the new benefits of ductility at stress levels which are important in the design and function of the casting.

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NOMENCLATURE

E	Elongation at failure, %
k	Constant, MPa/%
P	0.2 % Proof Strength, MPa
P^o	Probable Proof Strength, MPa
Q	Quality Index, MPa
T	Ultimate Tensile Strength, MPa

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