Paper No. 677

A STUDY ON THERMAL CRACKING OF CAST IRON

Dr. M. Yousaf Anwar

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ABSTRACT

The cast iron moulds are widely used in many glass moulding applications. During these processes, the moulds are continuously subjected to rapid heating and cooling which eventually causes failure due to thermal cracking. During the present study, the effects of heat-treatment on thermal cracking of cast iron were studied. From the results obtained it seems that the most important factor affecting the resistance of cast iron to thermal cracking is the apparent modulus of elasticity of the cast iron. It was found that heat-treatment, especially annealing, had an important influence on the thermal cracking of cast iron, but only to the extent that they affected the modulus of elasticity.

Keywords: thermal cracking, modulus of elasticity, moulds, heat-treatment.

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INTRODUCTION

The present research work was undertaken as an attempt to elucidate the significance of heat-treatment on the propensity of cast iron to thermal cracking. The reason this investigation was thought necessary was that in glass industry the vast majority of the moulds used are made of cast iron. Some moulds give long and satisfactory lives while others fail very rapidly. The premature failure is almost always due to the thermal cracking of the mould face, and it is this type of failure with which the present work is primarily concerned.

The function of the mould is quite simple; it is to enable a 'blob' of molten glass to be quickly and economically transformed to the desired shape. To be successful the mould must be able to conduct a certain amount of heat rapidly away from the glassware thus enabling it to retain its shape on removal from the mould. The mould is then cooled in order to be able to receive the next blob of glass. It is this rapid heating and cooling which eventually causes failure.

The conflicting properties required for moulds make it clear that no perfect material for the purpose exists. Of the several properties required probably the most important are:

(i) The material must be readily machineable and be able to impart a good surface finish to the glassware produced.

(ii) It should resist growth, oxidation, and other deterioration at high temperatures.

Other important properties are resistance to wear, high thermal conductivity and low thermal expansion. All these properties are required in addition to a high resistance to thermal cracking. From this it might be thought surprising that cast iron moulds are widely employed in the foundries and glass industry, the reason is quite simple that despite the fact that more modern alloys have been developed they do not seem to be able to satisfy this wide variety of requirements as well as does cast iron. Thus, despite its many limitations unalloyed grey cast iron is by far the most commonly used mould material. As working conditions become more severe the practice seems to be to add nickel, chromium or molybdenum to the iron. One cast iron containing 20 % nickel is said to be useful up to an operating temperature of 800 ^{o}C, while another one containing 36 % Ni and 30 % Cr with some additions of Si and W is stated by Oberlies and Dierzel [1] to be satisfactory for services at 1050 ^{o}C. Guillamon [2] recommends a 35 % Ni cast iron for very high temperatures.

MECHANISM OF STRESS FORMATIONS IN GLASS MOULDS

In glass moulding the mould face is alternatively subjected to the intense heating action of the 'blob' of glass and then rapidly cooled by air jets. When the molten glass is introduced it will cause rapid expansion of the extreme surface layer of the mould. This expansion will be restrained by the cooler underlying metal of the mould and as a result of this restraint expansion will take place into the cavity of the mould. This will cause contraction and will leave the working face of the mould in a state of stress if any plastic deformation occurred. Almost immediately after deformation has occurred the mould will be opened and surface cooled by air jets, and by conduction to the rest of the mould. This will cause contraction and will leave the working face of the mould in a state of stress if any plastic deformation occurred. If this stress exceeds the tensile strength of the metal then fracture will occur [3]. On the other hand if the stresses produced do not exceed the tensile strength of the metal, cracking will not occur at first. However, cracks may develop at some later stage. The number of applications of stress required to cause cracking will depend on the magnitude of stress developed in relation to the fatigue resistance of the surface layers of the metal. If the stress developed does not exceed the fatigue limit of the metal in the surface layers of the mould, cracking would never be expected to occur. With cast iron, however, this picture may be complicated by growth and oxidation both of which can occur during the life of the mould.

EXPERIMENTAL

The simple tests employed for the study of thermal cracking of cast iron may consist of quenching a test piece from a uniform high temperature. This treatment may not give similar conditions to those arising during glass muoulding where a temperature gradient exists across the mould body before cooling. In order that working conditions might be more nearly approached one face of the test piece had to be rapidly heated to a uniform high temperature and then rapidly cooled.

By using high frequency induction and a pancake coil placed a certain distance away from the test piece some resemblance to working conditions could be obtained. A disadvantage was that the periphery of the heated face became far hotter than the centre of the face. The resulting temperature gradient was unlike service conditions and seemed likely to lead to difficulties when an attempt was made to study the effect of temperature. The temperature gradient across the heated face was reduced by modifying the coil. This modification allowed the required temperature gradient down the sides of the test piece to be retained. The main disadvantage with high frequency method of heating was that the coil and test piece was extremely critical leading to difficulties in standardizing testing conditions. This was the main reason that this method of heating was eventually abandoned. Another difficulty arose in measuring temperature. In an attempt to do this a chromel-alumel thermocouple was spot welded to the test piece. On heating, the thermocouple wires became hotter than the surrounding metal and gave rise to erroneous results. Despite these difficulties a few test pieces were subjected to the test but it quickly became apparent that simply cooling in air was not sufficient to cause cracking in a reasonable length of time, and so water quenching was adopted.

The original test pieces were cylinders of 2 inches diameter and 2 inches height. During the heating period these were supported on two movable syndario shelves. When the test piece attained the desired temperature, it was allowed to drop into a tank of cold water, agitated to give rapid cooling.

To avoid the above mentioned difficulties, the test pieces were heated in a muffle. To make these test pieces single bars, 12 inches long by 2 inches diameter, were cast in a vertical green sand mould. The cast bars were sand blasted and machined down to 1.75 inches diameter. The top and bottom was drilled for analysis and then discarded, the rest of the bar was cut into discs of 0.75 inch thick.

These test pieces after heat-treatment were placed on 2" diameter carbon discs in an electric muffle at the required temperature and soaked for one hour. They were then quenched individually into a large capacity water tank, this quenching treatment was repeated. After each quench the test pieces were visually examined for cracks. After quenching for the required number of times the test pieces were carefully shot blasted subjected to magnetic crack detection and photographed. They were then sectioned and micro-scopecally examined using standard techniques.

RESULTS AND DISCUSSION

The charge consisting of Pig Iron and scrap was melted in a basic high frequency furnace. In each of these casts half the number of test pieces were cast against chills 3/8 in. thick by 2 in. diameter and half were cost without chills. In all cases the castings were allowed to cool in the mould before being cleaned, heat treated and machined. The chill cast test pieces in each case were too hard to machine and so had to be ground.

Composition of the Cast: T. C. = 3.15%, Si = 2.82%, S = 0.096%, P = 0.83% and Mn = 0.65%.

The bars were heat treated before tensile test pieces and thermal cracking test pieces were machined from them. The heat treatment consisted of annealing at 830 ^{o}C for four hours and while some other specimens were held at 830 ^{o}C for two hours before being oil quenched and tempered at 475 ^{o}C for two hours. The results obtained for these bars are given in Table 1.

Table 1: Apparent modulus of elasticity of 'as cast' and 'heat treated' samples

Specimens	Cycles to crack	Apparent modulus of elasticity, Lbs/in^2
As Cast	6	12.0×10^6
Annealed	13	10.4×10^6
Oil Quenched & Tempered	8	11.6×10^6

The microstructures of as cast specimens consisted of graphite flakes, ferrite, pearlite and phosphide eutectic, Figure 1. Figures 2 and 3 show that the amount of each constituent varied with heat treatment. In the as cast test pieces the amount of free ferrite was small, the lowest combined carbon obtained by analysis being 0.69%. In some cases free ferrite was completely absent.

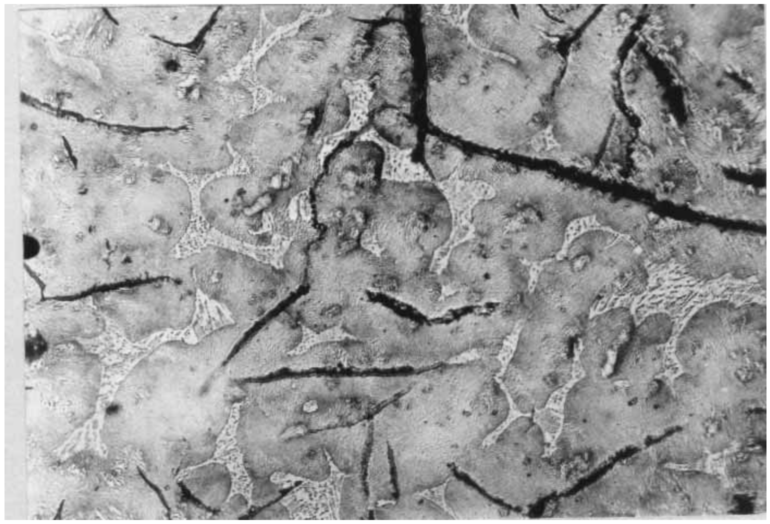

Figure 1: A microstructure of a as cast sample showing graphite flakes, pearlite and phosphide eutectic. Etchant 4% Picral. X 400

Quenching and tempering did not give rise to typical quenched and tempered structures but simply to an increase in the amount of free ferrite in the microstructure, Figure2. Annealing increased this still further, Figure 3.

Probably the most important feature revealed by the microscopical examination was that the cracks produced in grey irons follow the graphite flakes, Figure 4. In some of the test pieces the cracks were also seen to follow the grain boundaries.

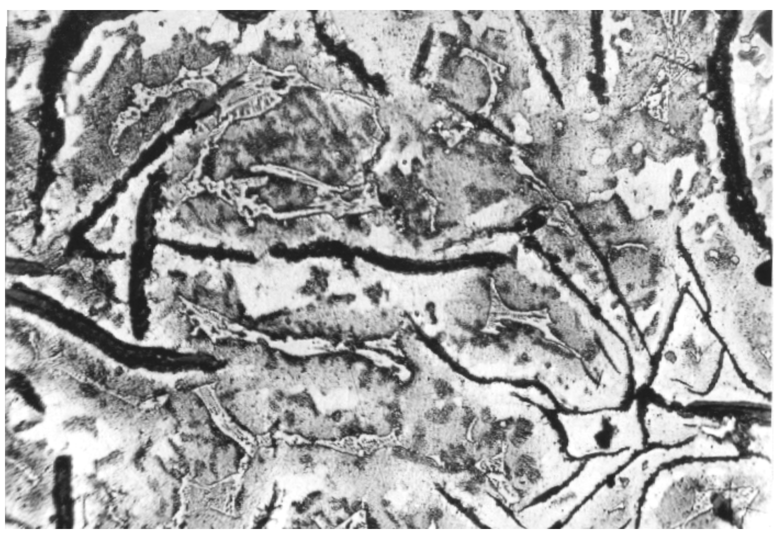

Figure 2: A microstructure of a quenched and tempered sample showing graphite flakes, pearlite, ferrite and phosphate eutectic. Etchant 4% Picral. X 400.

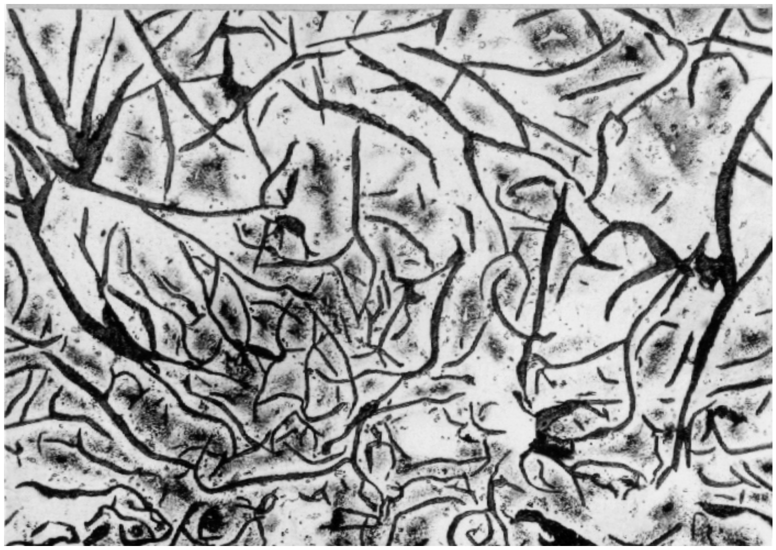

Figure 3: A microstructure of an annealedsample showing graphite flakes, ferrite and pearlite. Note difference in graphite flake form. Etchant 4% Picral. X 400.

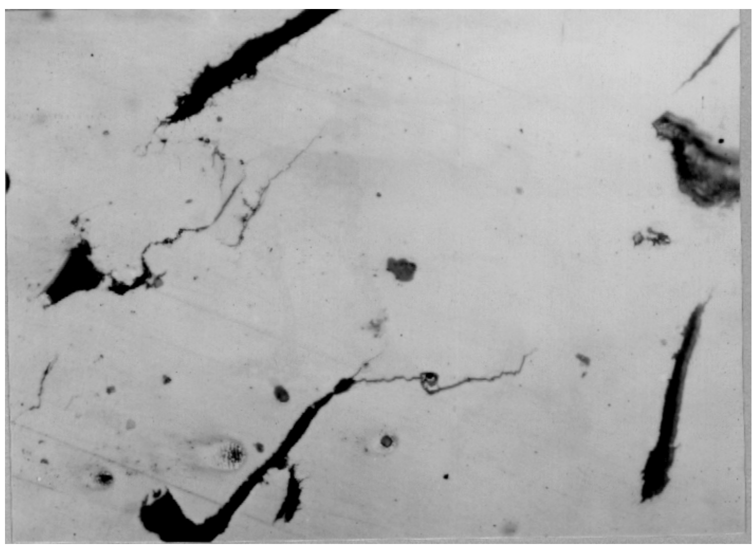

Figure 4: A microstructure of a sample quenched six times from 600 ^{o}C, showing small cracks originating at ends of graphite flakes. Unetched, X 400

The microstructures of chilled cast specimens showed that the chilling had been too severe resulting in the production of white iron. The cracks produced in these irons were found to follow the dendrites from the surface, but in no case did they proceed deeper than the point at which the first graphite flakes were evident. Figure 5 shows cracks produced in some test pieces after 20 cycles of cracking test.

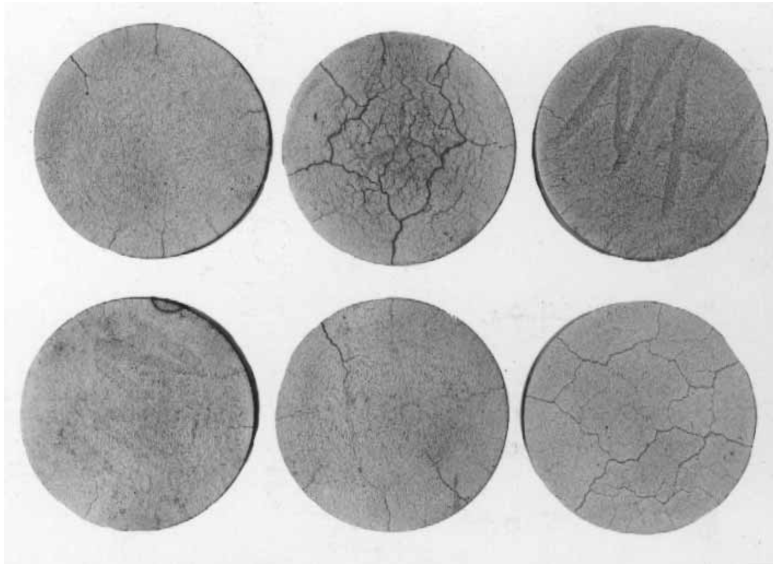

Figure 5: Some test pieces after 20 cycles of cracking test.

The most beneficial heat treatment was always found to be annealing. It seems likely that this is due to the fact that it lowers the apparent modulus of elasticity of the iron. The changes in microstructure and hardness support this assumption. The beneficial effect of annealing is in agreement with the findings of Smith [4] and with those of Oberlies and Dietzel [1] who found that under actual working conditions irons having low combined carbon contents had greater resistance to thermal cracking than irons having higher combined carbon contents.

In quenched and tempered condition, however, the rate of increase in life is not so great as in annealed conditions. This suggests that as a result of the oil quenching treatment from above AC_3 small cracks may have been formed in the cast irons. Microscopical examination, however, did not reveal any such cracks at a magnification of X 500.

CONCLUSIONS

The most important factor affecting the resistance of cast iron to thermal cracking is the apparent modulus of elasticity of the iron. The most beneficial heat treatment is found to be annealing. It seems likely due to the fact that annealing lowers the apparent modulus of elasticity of the iron.

ACKNOWLEDGEMENT

The help and support of the technical staff and chairman of the Engineering Materials Department, University of Sheffield, UK, in providing the melting and testing facilities to the author is gratefully acknowledged.

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