THE ROLE OF SHARP NOTCHES IN GOVERNING THE STRENGTH-FRACTURE CHAHACTERISTICS OF SONE STRUCTURAL ALLOYS

دور الحزوز الحادة فى التحكم فىخصائص الكسروقوة التحمل لبعض السبائك الانشائية

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خلاصـــة :

من المعروف أن وجود الحزوز فى الأجزاء الميكانيكية عموما يضعف هذه الأجزاء ويؤدى الى تقليل عمــــر تشغيلها . ولكى نضمن الأمن والاعتمادية لهذه الأجزاء فانه من الضرورى أن نتمكن من تحديدالدورالذى تؤديـــه الحزوز فى التحكم فى قوة التحمل وخواص الكسر للمواد .

وفى هذا البحث تم اختبار عينات من بعض السبائك الانشائية لتعيين مقاومة الكسرلهذه السبائك تحت تأثير الأحمال الاستاتيكية وفى وجود الحزوز الحادة . وقد صنعت عينات الاختبار المحززة والغير محززة من الزهــــر المرن والزهر الرمادى بالاضافة الى نتائج مأخوذة على عينات من سبائك الألومنيوم عالىالمقاومة من نوع٧٠٧٥وكذلك عينات من النحاس الأصفر . وقد تم تصنيع كل من الزهرالمرن والزهر الرمادى المستخدمين فى تجارب هـــــذا البحث فى ورشة السباكة بشركة المحلة للغزل والنسج .

تبين نتائج البحث أن قوة تحمل العينات المحززة تتناقص مع زيادة عمق الحزوز بصفة عامة كما وجـــد أن التخفيض فى مقاومة الكسر للسبائك المختبرة تعتمد على ما اذا كانت السبائك قصفة أم مطيلة . فالزهر المـــرن المعروف بأنه يظهر تصرفا مطيلا أظهر حساسية محدودة للحزوز حيث حدث انخفاض محدود فى مقاومة الكســــر نتيجة لوجود الحزوز الحادة . ومن جهة أخرى فان الزهر الرمادى وهو مادة قصفة قد مارس انخفاضا حادا فى مقاومته للكسر نتيجة التحزيز . وقد انطبقت النقاط التجريبية للسبائك الأربعة على التصرف المتوقع والذى تـــم التعبير عنه بمعادلة رياضيـــة عملية تعين المصمم على التنبوء بتأثير الحزوز على مقاومة الكســــر لهـــــذه المـــواد .

1. ABSTRACT:

The presence of notches in engineering components generally weakens these components and leads to a reduction in their operational life. In order to ensure safety and reliability, it is necessary to be able to predict the role of the notches in governing the strength and fracture characteristics .

In this research, specimens made of some structural alloys have been tested to determine the fracture resistance of these alloys under static loading and in the presence of sharp notches. Notched and un-notched specimens were made of ductile and grey cast irons in addition to data taken previously on high strength aluminum alloy of type 7075 and brass. Both ductile and grey cast irons were manufactured in the foundary workshop of Mahalla Spinning and Weaving Company.

Test results show that the reduction in the fracture resistance for the tested alloys depends on whether the alloy is ductile or brittle. Ductile cast iron which is known to exhibit ductile behaviour showed low sensitivity to notching where limited reduction in the fracture strength occured due to the presence of sharp notches. Grey cast iron being a brittle material, on the other hand, experienced severe reduction in the fracture strength. Experimental points for the four structural alloys are seen generally to follow closely expected behaviour for ductile and brittle materials. This behaviour has been expressed mathematically by an empirical formula.

2- INTRODUCTION:

For technological reasons, mechanical components often have complex shapes and may contain geometric discontinuities and metallurgical defects. These discontinuities, in addition to weakening the components by reducing the cross-sectional area, they reduce the strength of the members by producing triaxial stresses of high magnitudes in the vicinity of the notch tip. In general, the determination of the maximum stress that a given component can withstand in the presence of any of the foregoing stress concentrators is the whole problem of safety against fracture in the presence of static loading. Such stress condition can be easily simulated by means of notches made with various depth and sharpness. This subject has been studied by many investigators and various methods of interpretation of test results for notched specimens have been presented [1-3].*

This paper presents another method of treating the problem of the fracture resistance in the presence of sharp notches and static loading. It gives an experimental study on locally manufactured ductile and grey cast irons. The test results are then joined with results previousty obtained on high streugth aluminum alloy of type 7075 and brass. This will help to cover a sufficient range of structural alloys.**

3. THEORETICAL BACKGROUND:

The presence of sharp notches and flaws in structural members affects its strength since they have the effects of reducing the cross-sectional area and raising the stress and strain in the vicinity of the notch. If the material of the member is highly ductile, the effect of plasicization is to reduce, or even eliminate entirely the increase in stress. There is an adaptation of the material and the effect of overstressing due to the notch is replaced by a concentration of plastic strain. This plastic strain may sufficienty blunt the notch tip so as to leave the reduced cross-sectional area as the only reason for loss of strength. On the other hand, if the material is brittle or has a low level of ductility, stress relief is not possible and strength drops-off faster than for ductile materials and fracture is caused by the normal stress at the notch. A notch-insensitive material is expected to exhibit a straight line relationship between the strength and the notch depth as shown in Fig. (1). Point (1) represents the case of a notch-free specimen and the strength is, therefore, a maximum. Point (2), on the other hand, represents an imaginary case in which the notch is made to occupy all of the specimen width and the strength will, therefore, be zero. A material which is notch-insensitive having a notch of depth a may be expected to have a strength equal, or close, to σ_1. If the material is sensitive to notching, its strength may be expected to be reduced to σ_1'. The same may be said about a specimen having a notch of depth a_2. That is to say that the strength-notch depth relationship will fall off faster than that for a notch insensitive material. The abovementioned relationship may be obtained by carrying out tension tests on notched and un-notched specimens.

4. EXPERIMENTAL PROCEDURE:

4.1. MATERIALS

Ductile cast iron is known to combine the process advantages of cast iron, namely fluidity and machinability, with mechanical properties close to those of steel, namely strength, ductility, and resistance to impact, wear and corrosion. For this reason, it has replaced steel under many conditions of use insofar as the mechanical properties and service requirements are concerned [6].

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* Numbers in brackets refer to references at end of paper.

** Test data for Aluminum Alloy-7075 and brass have been taken from some unpublished work made by the author.

Since the discovery of this type of cast iron, it has attracted the attention of numerous investigators to evaluate its physical and mechanical properties as compared to those of steel [1,2]. There also exist a number of specifications for ductile cast irons which include those of the Society of Automotive Engineers, the American Society for Testing Materials, Army Ordance, the United States Navy Department, and the British Standards. [2,7]. For these reasons, ductile cast iron was selected, with the other alloys, as a test material.

Test specimens have been prepared from pearlitic structure ductile and grey cast irons having chemical compositions as shown in Table (1) and (2).

Table (1) Chemical Composition of Pearlitic Structure Ductile Cast Iron.

C %	Si %	Mn %	P %	S %
3.4	2.6	0.3	0.04	0.015

Table (2) Chemical Composition of Pearlitic Structure Grey Cast Iron.

C %	Si %	Mn %	P %	S %
3.3	2	0.6	0.4	0.05

the ductile and grey cast irons used in the study have been manufactured in the foundary workshop of El-Mahalla Spinning and Weaving Co. Using the Vortex method outlined in Reference [8].

4.2. TEST SPECIMENS:

Test specimens have been prepared according to ASTM Standard-as shown in Fig. (2). Circular and rectangular cross-section specimens have been prepared with V- groove or side sharp notches. The following Table summarizes the data of the specimens tested.

It is known that the notch angle and tip radius influence the fracture characteristics. In order to isolate such effects, the notches have been made with the same angle and tip radius. This was achieved by using a fresh V-shaped forming milling cutter of 45 degrees for each group of tests. The notches were observed in a Vicker's hardness microscope, and the tip radii were found to have an average value of 0.2mm. The notch depth varied from 0 to 6 mm while the width of the specimens have a nominal value of 20 mm.

Table (3) Data for the test specimens.

No. of Specimens	Cross-section	Type of Notch	Material
4	rectangular	45-V	ductile cast iron
4	rectangular	45-V	grey cast iron
4	circular	45-V	Ductile cast iron

4.3. TEST EQUIPMENT:

Tension tests have been carried out on un-notched and notched specimens on a German made hydraulically operated universal testing machine Model ZD 20. The chart speed of the x-y recorder was adjusted at 2 in. (51mm) per minute and the head speed was adjusted at 0.5 in. (12.75 mm) per minute.

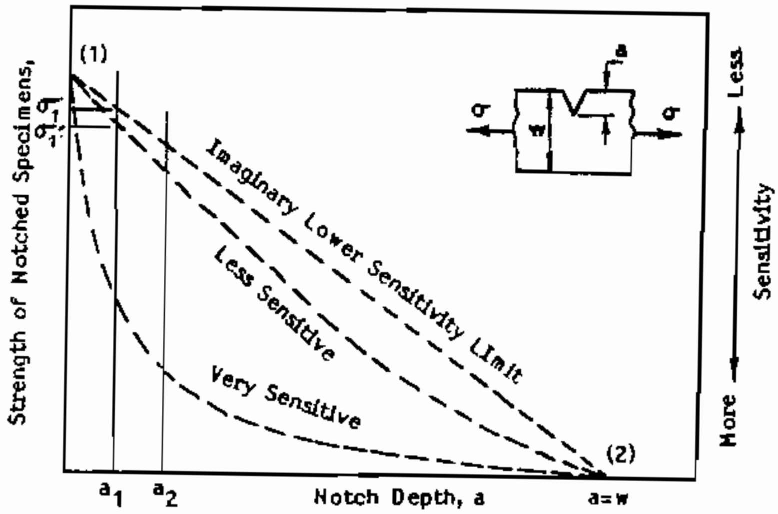
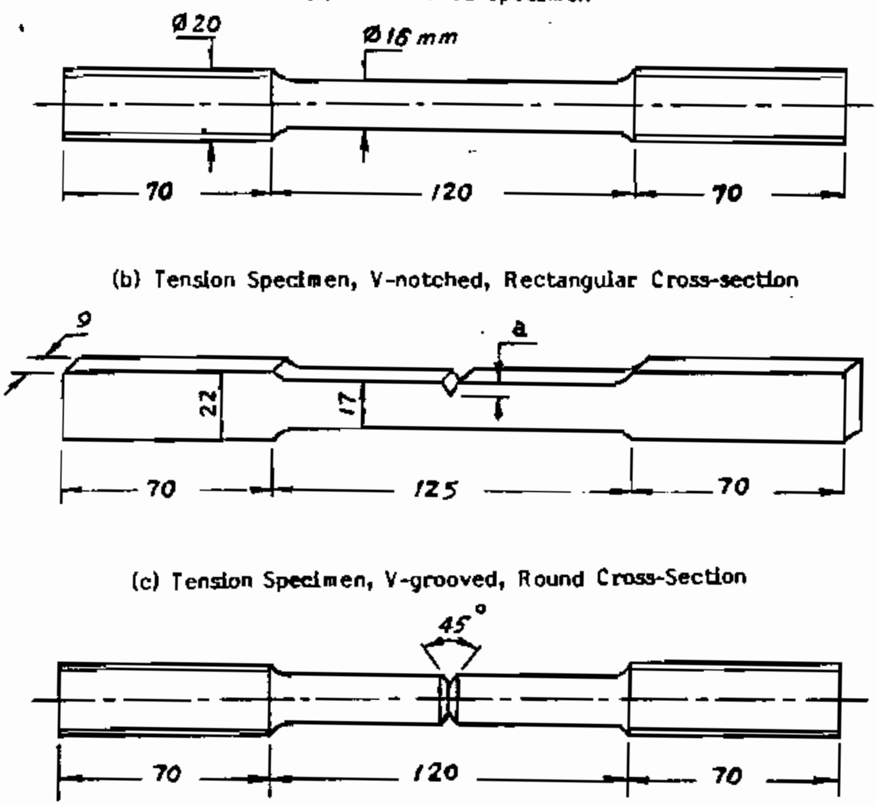


Fig. (1) Hypothetical Relationship between Strength and Notch Depth

(a) Un-notched Specimen



(b) Tension Specimen, V-notched, Rectangular Cross-section

(c) Tension Specimen, V-grooved, Round Cross-Section

Fig. (2) Configuration of Test Specimens,

5.TEST RESULTS AND DISCUSSION:

Fig. (3) gives a graphical representation of the experimental data and the results obtained for the test materials. Best fit lines are drawn to connect experimental points . In Fig. (3), the ratio of the fracture stress of the notched to that of the un-notched specimens, the fracture strength ratio FSR, is plotted as a function of the ratio of notch depth to specimen width, a/w. The variation of the work of fracture and the percentage elongation of both ductile and grey cast iron are shown in Fig. (4). Test results indicate that the strength of notched specimens generally decreases as the notch depth increases. Experimental points of the metals tested in the study are seen to follow closely the expected behaviour. For ductile cast iron, for example, the experimental points fall approximately on the imaginary lower seusitivity line. This observation indicates that ductile cast iron behaves as a typical ductile material regarding various mechanical properties including resistance to static fracture. A similar behaviour is observed for the aluminum alloy. On the other hand, grey cast iron and brass exhibited quite severe diviation from the imaginary lower seusitivity line. Their strength dropped sharply due to the presence of sharp notches; and the drop increases rapidly as the notch depth increases. At a notch depth to specimen width ratio, a/w, of 0.32, for example, the strength of grey cast iron decreased by abut 86% while for ductile cast iron, the decrease was only about 38%.

Such a behaviour may be described mathematically by an empirical formula of the form:

$$\text{Fracture Strength Ratio} = FSR = \frac{\sigma_{u\,\text{notched}}}{\sigma_{u\,\text{unnotched}}} = 1 - \left(\frac{a}{w}\right) f\,(d)$$

where f (d) is an assumed ductility function which should be approximately unity for ductile materials; and is higher than unity for brittle materials.

Based on experimental results of Fig. (4), the ductility function, f (d), is evaluated as shown in Table (4).

Table (4) Experimental values of f (d)

Material	Ductile C.I.	Grey C.I.	Alum.Alloy	Brass
f(d)	1.1	2.875	1.4	2.1

Other properties which are relevant to the fracture process and were determined from the test data were the work of fracture, which is the work expired during the fracture process and is measured from the area under the load-deformation curve, and the percent elongation of the fractured specimens. The two quantities were plotted as functions of the notch depth. As shown in Fig. (4), both the work of fracture and the percent elongation represent decaying functions with the ratio a/w for both materials. Moreover, the ratio of the work of fracture for ductile and grey cast irons is about 3 and as the notch depth innreases, the work of fracture decreases and this ratio increases rapidly reaching a value of about 8 as the notch depth occupies about one-third of the specimen width. Similar behaviour can be observed for the percent elongation. This indicates that however ductile cast iron acts as a ductile material, the presence of sharp notches decreases its ductility and enhances the brittleness of the material causing the fracture strength to decrease. This explains the experimental curve of ductile cast iron being very close to the imaginary lower sensitivity limit in Fig.(3). For brittle materials, on the other hand, the sensitivity to notches is quite high and the reduction in the fracture strength is severe. In highly ductile materials, plastic constraints are developed at the notch

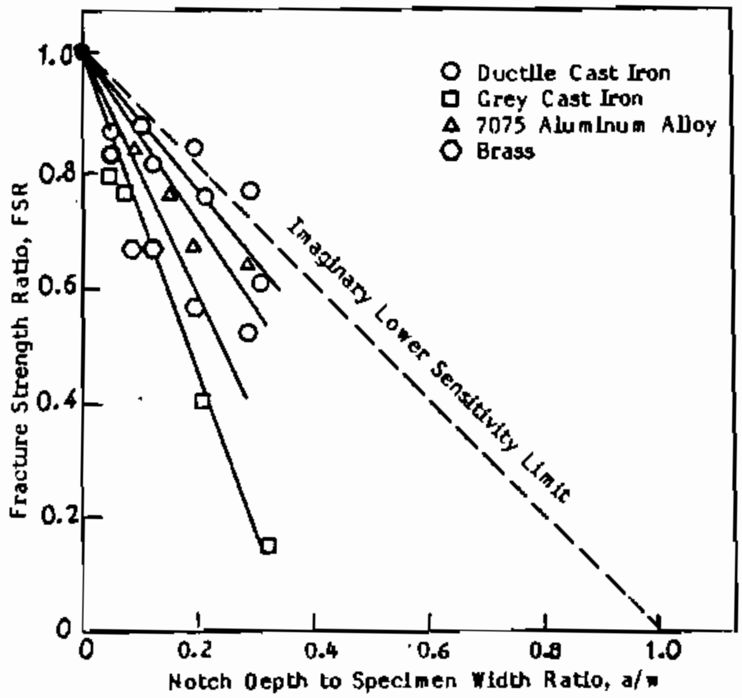


Fig.(3) Fracture Strength Ratio versus Notch Depth to Specimen Width Ratio

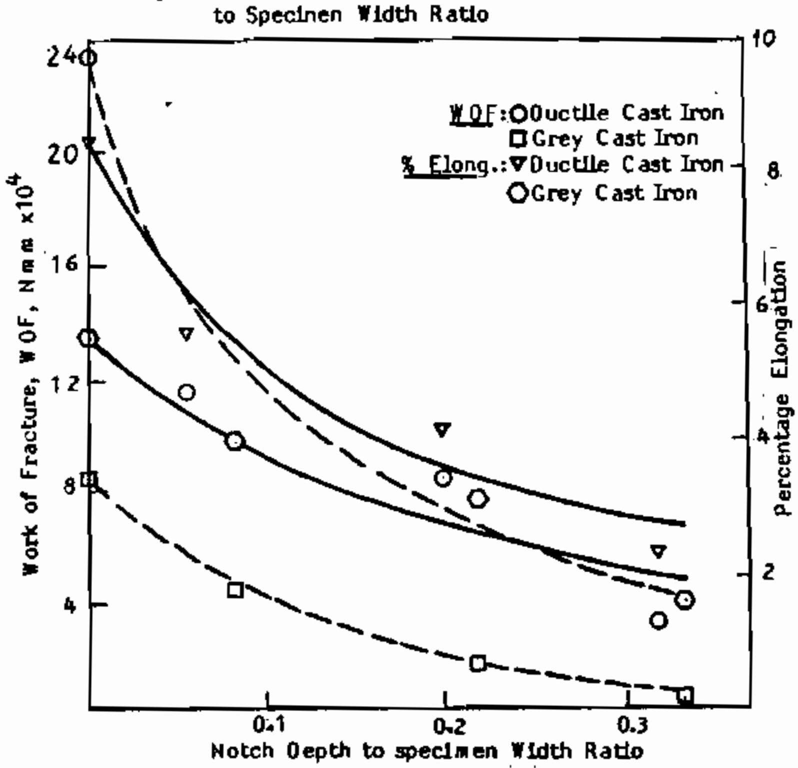


Fig. (4) Work of Fracture and Percentage Elongation Versus Notch Depth to Specimen width Ratio tip causing relief of the effect of the stress concentration.

CONCLUSIONS:

It may be concluded from the abovementioned results that the strength of ductile cast iron is insensitive to notches. Expected severe reductions in strength due to the presence of notches appeared in brittle materials such as grey cast iron where the tensile strength was reduced by more than 80%. The behaviour of ductile cast iron, on the other hand, resembled that of a ductile material in that no severe reduction in strength occured. The blunting process at the root of the notch relieves the stress concentration caused by the notch at its tip.

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