Effect of Micro-Sized on Thin plate Specimen using Fractographic Analysis

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ABSTRACT

In the last four decades, the car body thickness has reduced significantly from almost 1.5 mm to below 0.5 mm. This was mainly due to the demand for weight reduction for saving more fuel cost. Besides being thinner, maintaining the high strength of car body was possible by using a newly developed high-strength steel thin plate. However, mechanical properties of bulk materials which usually tested using a standard big size sample are not necessarily representing the actual properties of the material when dealing with very thin and small size components. This drives the research on the mechanical properties of the micro-sized specimen for the production of tiny metal-based components. In this study, tensile and fracture behaviors of the micro-sized specimen were investigated. The materials used were 100 and 300 micron stainless steel S304 thin plates, the tests were carried out on specimens of ASTM A313M spring steel materials. The results showed that 100 micron thin plate exhibited higher tensile strength with no clear evidence of yielding as compared to 300 micron plates. The fracture morphology images observed by Scanning Electron Microscopy (SEM) revealed that both specimens fractured in ductile mode. Formation of dimples on the fracture surface could be recognized easily in 300 micron sample at higher magnification as compared to 100 micron sample.

Keywords: Micro-sized specimen, Tensile test, Fracture behavior, Thin plate, S304 steel

تأثير العينات الصغيرة على الصفائح المعدنية باستخدام الكسر الجزيئي

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الخلاصة:

لغرض خفض الوزن لتوفير المزيد من تكلفة الوقود وتقليق كلفة الأنتاج إضافة إلى كونه أرق، والحفاظ على قوة عالية من جسم السيارة لقد لوحظ في العقود الأربعة الماضية، قد قلل من سماكة جسم السيارة بشكل ملحوظ من حوالي 1.5 ملم إلى أقل من 0.5 ملم وذلك باستخدام الواح الصلب الرقيقة عالية القوة. ومع ذلك لوحظ عند استنتاج الخواص الميكانيكية للمعادن المستخدمة التي تم اختبارها عادة باستخدام عينة كبيرة الحجم القياسية لا تمثل بالضرورة الخصائص الفعلية للمواد عند التعامل مع المكونات ذات الأحجام الرقيقة جدا والصغيرة. هذا يدفع للبحث على الخواص الميكانيكية للعينات الصغيرة الحجم لإنتاج مكونات القائمة على المعادن صغيرة. في هذه الدراسة، تم التحقيق من سلوكيات الشد والكسرلالعينة الصغيرة الحجم. وكانت المواد المستخدمة

100و300 مايكرون من الفولاذ المقاوم للصدأ وقد أظهرت النتائج أن الصفائح الرقيقة ذات 100 ميكرون أظهرت ارتفاع قوة الشد مقارنتا مع الألواح ذات 300 مايكرون وكذلك لوحظ من خلال المجهر الألكتروني ان جميع العينات قد كسرت في وضع الدكتايل. علما ان المقايسة المريكية اي اس تي ام 313 ام.

الكلمات المفتاحية : العينات الصغيرة , فحص الشد , سلوك الكسر, الصفائح الرقيقة , ستيل 304

INTRODUCTION

Stainless steel is a material widely used in the industrial sector in line with technological developments. Properties of stainless steel make it suitable for components stressed. It is stainless steel, high-stress value and the ability to operate at high temperatures allows it to become widely used. The fact that material properties change with specimen size has been well known for several years [1, 2]. In recent years, the market demand at the micro level such as pin connector, micro screws, springs, IC sockets, micro gears and micro shaft so has increased significantly as a result of the downsizing of the product. Micro components have also been widely used in many industries including automotive, biomedical, aerospace and electronics. Miniaturization technology has become more important in the fabrication of micro parts. When the size of the decline to the microscale changes in the mechanical behavior of materials and the effects of the so-called size effect [3]. Effect size is characterized by grain size, the size of the specimen and the size of the surface topography. The mechanical properties of the material properties that expose the behavior of elastic and non-elastic when a force is applied thereby indicate its suitability for mechanical applications. Such as modulus of elasticity, tensile strength, elongation, hardness and fatigue limit [4] .The tensile test is one method of evaluating the structural response of steel to the applied force, with the result expressed as a relationship between stress and strain.

This work examines the backdrop of stainless steel S304 specimens, which affects the experimental method. The experimentation was held out on specimens having different thicknesses to test tensile fracture behavior of dislocation density specimens. An experiment conducted on a specimen size of 0.1mm and 0.3mm micro. This research involves the use of some equipment that Universal Testing Machine (UTM), machine polish and scanning electron microscopy. Before the tests are done by using the universal testing machine was going through the process of heat treatment of quenching, it is intended to restore the mechanical properties and microstructure of specimens repairs. Dumbbell-shaped specimens will be used for this form easily held by the machine, and the effect of fracture is clearly visible on the specimen.

EXPERIMENTAL PROCEDURES

Material and Specimen

The material used was a type stainless steel S304. The chemical composition of the material (wt. %) is listed in (Table 1). Dumbbell-shaped specimens with a thickness of 0.1mm and 0.3mm were machined as shown in (Fig.1). The dimensions of the specimen under a millimeter in size used for both stainless steel S304 specimens of different thickness. Emery paper mechanically polished the specimen surface, then buff-finished before the experiment. The microstructures before and after the tensile test with a thickness of 0.3mm and 01mm are shown in (Fig. 2 (a, b, c, d)). The specimens with a thickness of 0.3mm have a strong atomic bonding between the layers upon layers that complicate it undergoes deformation to slip from its original form. While for specimens with thickness 0.1mm bonds between atoms are weak layer after layer and makes it easy to slip from its initial position.

Procedure

These experiments involved the use of stainless steel S304 dumbbell-shaped. Experiments will be performed on specimens with a thickness of 0.1mm and 0.3mm. Initially, the specimen underwent quenching in a furnace at 700°C for one hour and cooled in the furnace. Micro-sized specimens only use emery paper mechanically polished the specimen surface grade (800-1200) for grinding process, then buff-finished using polishing machines before the experiment. To obtain microstructure on the surface of the etched specimen process will be carried out in (5-7 Sec). After the tensile tests are performed on the specimen thickness of 0.1mm and 0.3mm by using the Universal Testing Machine (UTM), tensile tests were performed on specimens cut off. This test is performed to obtain the mechanical properties of the material. Effects fracture of

Fractographic Analysis.

Fracture surface observations carried out to identify the mechanism of tensile test fracture of stainless steel S304. The fractography observation shows, two specimens observed, a 1st specimen with thickness 0.1mm and 2nd specimen thickness of 0.3mm, which has done the tensile test represented by (Fig. 5). Through observation, the discussions focused on the differences on the surface of the specimen due to the effect of specimen thickness. The significant difference was seen the pattern, the cleavage and dimples in the fracture surface.The tensile test will be observed by using a Scanning Electron Microscope (SEM).

RESULTS AND DISCUSSION

In this work, we conducted micro-tensile tests and fracture behaviors for stainless steel S304 specimens with two different thicknesses 0.1mm and 0.3mm to evaluate the mechanical properties of the micro-sized specimen, the production of tiny metal-based components.

Tensile Test Analysis

The stress–strain curves shown in (Fig. 3, Fig. 4) Obtained from the micro-tensile test of 0.1mm and 0.3mm thickness stainless steel S304 specimens respectively. The micro-tensile test was conducted using three micro-specimens labeled as a specimen A, B and C in each figure. The micro-tensile test for specimen 0.1mm thickness, as indicated in (Fig. 3) The stress–strain curve at the beginning of the elastic stage stainless steel S304 is the same. Changes in readings between specimens A, B and C occur when the specimen reaches the ultimate strength. Specimen C has the ultimate strength higher than that of specimens A and B. Therefore, the experiments on specimens with a thickness of 0.1mm can be formulated continuous tension is applied to the specimen will enter the phase of strain hardening up at one stage graph shows. The specimen experienced a dislocation or plastic deformation, in this case, the specimen will begin to an extension. The appearance of small cracks will grow and subsequently subjected to continuous tension will break the specimen.

Meanwhile, the micro-tensile test for specimen 0.3mm thickness, as shown in (Fig. 4) the difference compared to a specimen of stainless steel S304 with a thickness of 0.1mm. While, The specimen of A, B and C have the high yield strength before reaching the ultimate strength and fracture point. The high yield strength of the specimens A was 810MPa, specimen B was 773MPa, and Specimen C was 774Mpa. Thus, the overall reading of the stress-strain curve between A, B and C specimens found there reading gap for both specimens but have the same pattern graph form so that the specimen was broken.

Based on the (Tables 2, Table 3) the yield strength values recorded between specimens with 0.3mm thickness readings showed no significant difference. However, for a specimen with a thickness of 0.1mm yield strength value is not specified because it does not involve one of the processes during plastic deformation. The ultimate strength of all specimens is shown in (Tables 2, Table 3) which have a thickness of 0.1mm, and 0.3mm show subtle differences. All specimens have an average ultimate strength between 1160Mpa up to 1163.33MPa. Specimens having a thickness of 0.1mm indicate high strength compared to specimens having a thickness of 0.3mm, but the difference was almost the same for both thicknesses. This experiment proves that the thickness of the sample does not affect the ultimate strength.

Then also (Tables 2, Table 3) shows the average breaking strength shows different flow, where the sample has a thickness of 0.1mm, has average breaking strength 1020Mpa. While, the sample thickness is 0.3mm has average breaking strength 976.67Mpa. So these experiments showed that the sample thickness of 0.1mm has high fracture resistance properties compared to 0.3mm thickness. The significant percentage elongation between specimens of different thickness also shown in (Tables 2, Table 3). Specimen 0.3mm thickness has a high percentage compared to the specimen of 0.1mm thickness. It showed higher thickness can elongation higher prior to fracture than the thickness of a thin specimen. That is lead to the thickness of a material affects the percentage elongation but does not affect the strength of a material. Theoretically stainless steel S304 specimen thickness 0.3mm has a higher elongation percentage due to the atoms in the metal lattice space will move during plastic changes occur and more energy necessary to ensure that, the process of dislocation occurs between the layers upon layers of metal lattice.

Overall, the tensile tests carried out showed that the pattern of changes in the yield strength, ultimate strength and breaking strength for each thickness of 0.1mm and 0.3mm. Pattern reading shows the ultimate strength readings for samples with a thickness of 0.1mm and 0.3mm is almost the same this proves that the thickness does not affect the strength of a material. This statement reinforced by [5], namely the percentage of different carbon will determine the mechanical properties of stainless steel. Improved reading on stainless steelS304 proves that the ultimate strength and breaking strength increased with the reduction in thickness of the specimen. This change occurs because when the grain size is more or less approaching the specimen thickness, the grain function plays a role in influencing the mechanical properties of stainless steel [6]. This situation is influenced by changes in the mechanical properties of polycrystalline to single crystal when the specimen geometry changes. Each grain will play a significant role influencing the changes in the properties of materials change [7]. With these changes in the thickness of the specimen makes the elastic properties of the material becomes very difficult due to the specimen fracture. However, the thickness of the sample is also influenced by the grain size diversity contained in the specimen thickness and resistance to dislocation movement of the specimen.

In the case of comparison magnifications 100X, 2000X for stainless steel S304 with a thickness of 0.1mm, and 0.3mm at (Fig. 5 (a),(b)). Moreover, based on the tensile tests results that's reinforced sample thickness 0.1mm have a lower elongation percentage compared to samples with a thickness of 0.3mm as shown in (Table 2, Table 3). Then, 0.3mm sample involves changes in yield stress but it did not happen in the sample of thickness 0.1mm. Can be concluded that the sample has a bond between the layers of 0.3mm strong grain and this makes it difficult to broken while the 0.1mm samples have weak bonds between the layers and less. Moreover, it is easier to be broken grain samples that have a strong bond between the coating will produce rough surface samples. These differences will affect the nature of the material. However, the pattern of both specimens fracture almost in the ductile mode because the sample surface rough, dark and fibrous then small scattered areas of cleavage fracture were seen.

The representative SEM fractography of the tensile fractured specimens with 10000X magnification shown in (Fig. 5(c)). The images showed a small grain size and arranged for a sample of 0.1mm and 0.3mm sample image shows the coarse grain size and unstructured. The fractographic observation shows that tensile fracture occurs mostly intergranular (typically dimple) fracture mode. That could be recognized easily in 300 micron sample at higher magnification as compared to 100-micron sample because the dimples are the concentration stresses area.

CONCLUSIONS

Based on our studies, some findings have been formulated as follows:

1) The microstructure showed that the specimens with a thickness of 0.3mm has a strong atomic bonding between the layers upon layers that complicate it undergoes deformation to slip from its original form. While for specimens with thickness 0.1mm bonds between atoms are weak layer after layer and makes it easy to slip from its initial position.
2) The stainless steel S304 samples produced in this tensile test study showed the thickness of the specimen does not affect the nature of the material. The results obtained from specimens of different thickness shown the ultimate strength of the material in the range matching. While, the percentage of elongation of the specimen thickness of 0.1mm and 0.3mm is different due to the influence of atomic bonding between the layers upon layers. Greater thickness will complicate the enactment of the derailment thereby increasing the percentage elongation of the specimen.
3) The fractographic analysis shows the pattern of both specimens fracture almost in the ductile mode. Then small scattered areas of cleavage fracture were seen for both samples. Formation of dimples on the fracture surface could be recognized easily in 300 micron sample at higher magnification as compared to 100-micron sample.

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Table (1): Chemical composition (wt. %)

C	**Mn**	**F**	**S**	**Si**	**Cr**	**Ni**
0.08	2.00	0.045	0.03	1.0	18.0-20.0	8.0-11.0

Table (2): Mechanical properties for stainless steel S304 with thickness 0.1mm

No.	**Yield strength at 0.2% (MPa)**	**Ultimate strength (Mpa)**	**Breaking strength (Mpa)**	**Elongation (%)**
A	1030	1170	1040	9.5
B	1020	1180	1010	6.6
C	1020	1140	1010	11.3
Average	1023.33	1163.33	1020	9.13

Table (3): Mechanical properties for stainless steel S304 with thickness 0.3mm

No.	**Upper Yield strength (Mpa)**	**Ultimate strength (Mpa)**	**Breaking strength (Mpa)**	**Elongation (%)**
A	810	1170	1010	27.5
B	773	1160	965	25.4
C	774	1150	955	26.4
Average	785.67	1160	976.67	26.43

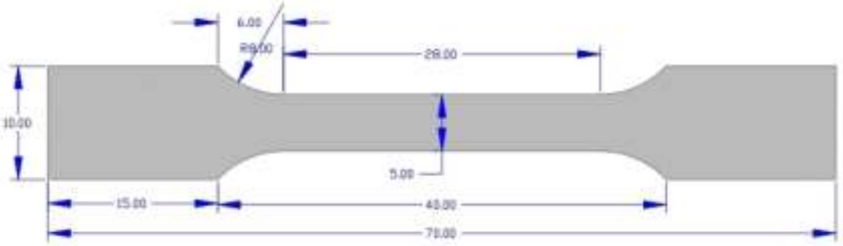


Figure (1): Specimen configuration according to ASTM 313M

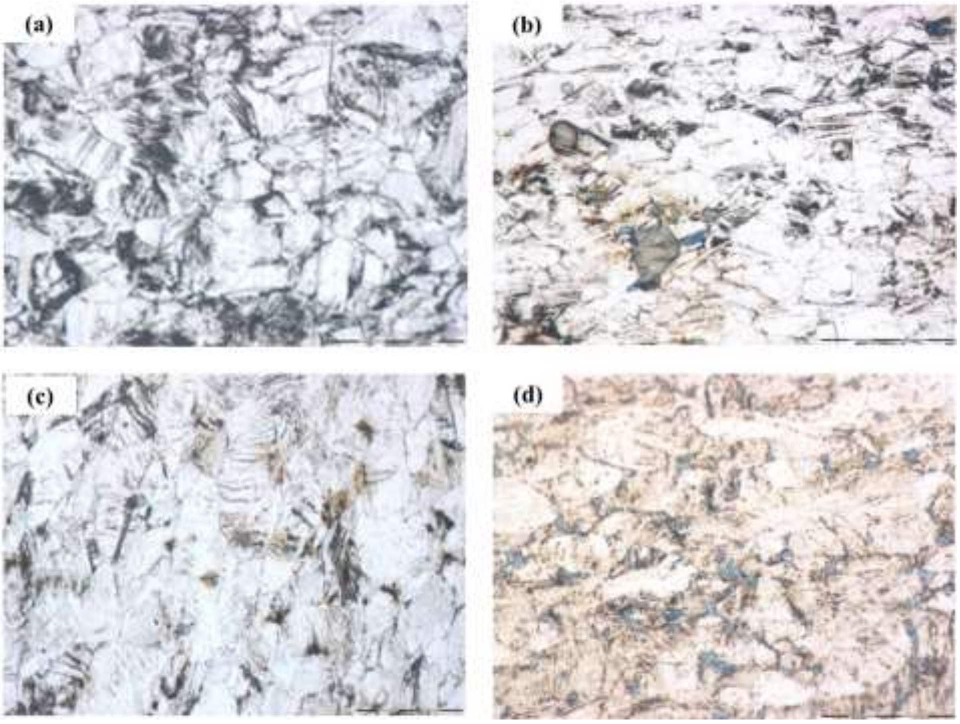


Figure (2): Microstructures of stainless steel S304specimens before and after the test tensile: (a) Before the test tensile t= 0.3mm at 50x magnifications; (b) Before the test tensile t= 0.1mm at 50x magnifications; (c) After the test tensile t= 0.3mm at 50x magnifications; (d) After the test tensile t= 0.1mm at 50x magnifications.

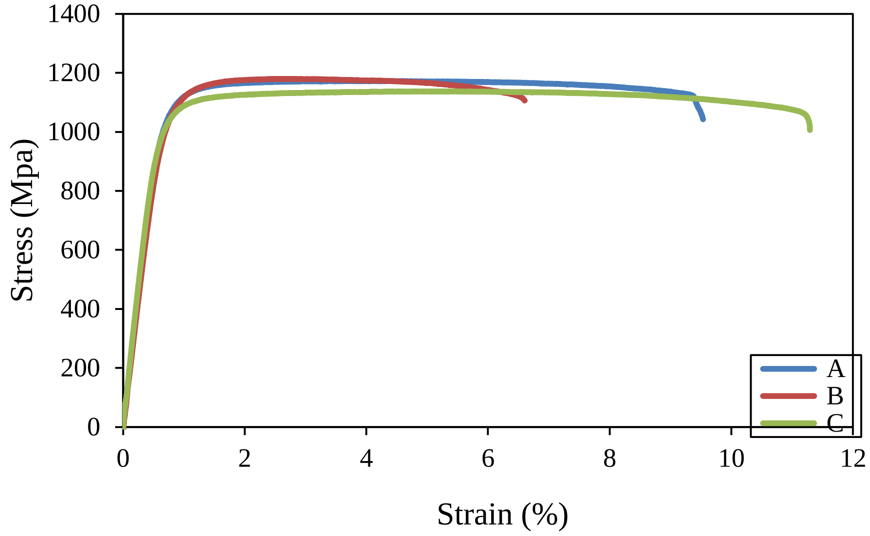


Figure (3): Stress-strain curves for specimens of stainless steel S304 at 0.1mm thickness

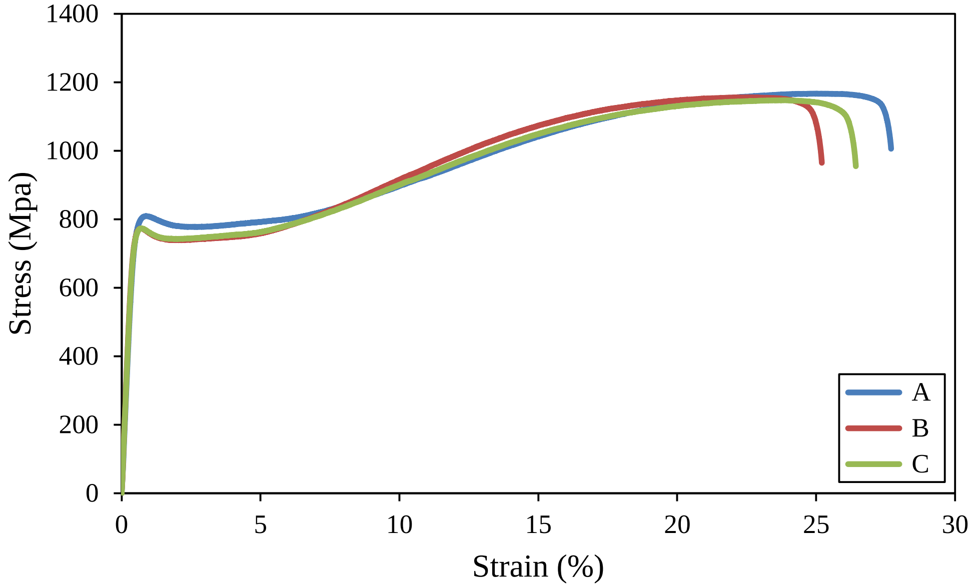


Figure (4): Stress-strain curves for specimens of stainless steel S304 at 0.3mm thickness.

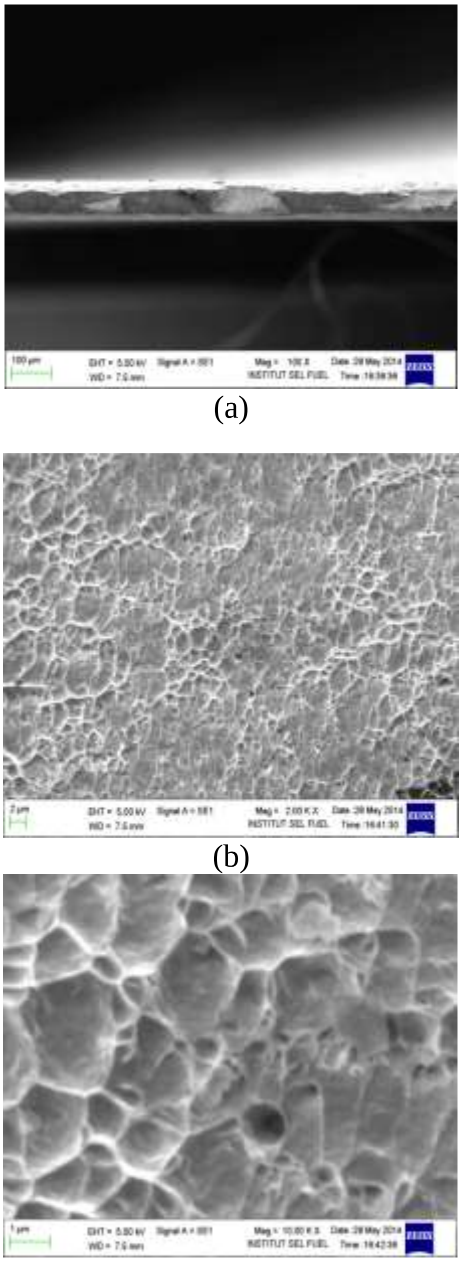
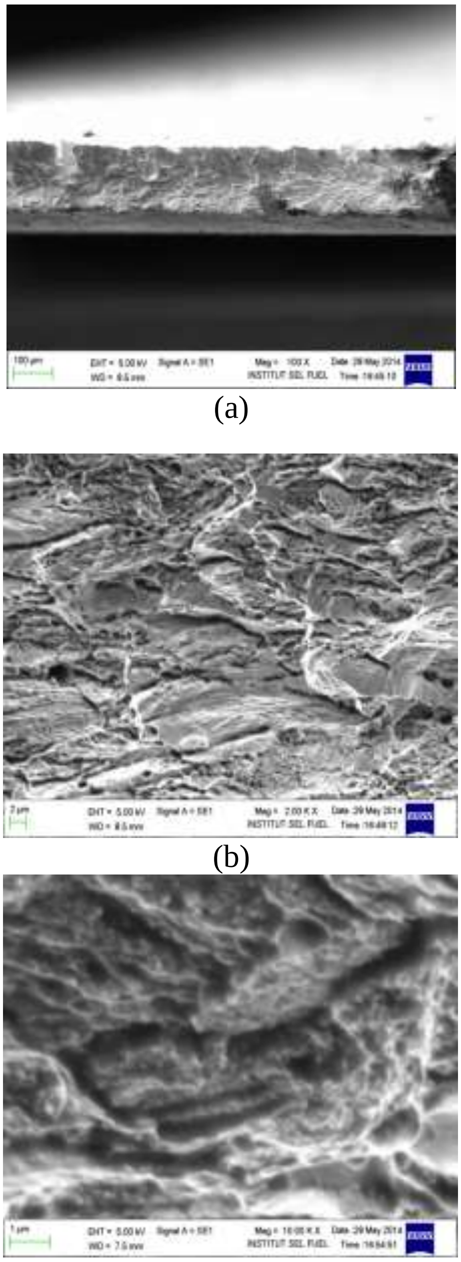
0.1mm specimen thickness	0.3mm specimen thickness
 (a) (b) (c)	 (a) (b) (c)

Figure (5): SEM fracture surface of tensile specimens, with a thickness of 0.1mm and 0.3mm stainless steel S304: (a) Magnification at 100X, (b) Magnification at 2000X, and (c) Magnification at 10000X.