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TENSILE AND FRACTURE BEHAVIOUR OF VERY THIN 304 STAINLESS STEEL SHEET

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Abstract

Specimen with rectangular cross-section usually used to measure the tensile properties of materials. However, the specimen size and thickness may affect the results. In this study, tensile and fracture behaviours of very thin 304 stainless steel sheet were investigated. The thickness of the stainless steel sheets investigated were 100 and 300 μm. Tensile samples were cut into dumbbell-shaped of rectangular cross-section with same width for both thickness according to ASTM E8. The results showed that 100 μm thin steel sheet exhibited higher tensile strength with no clear evidence of yielding as compared to 300 μm sheet. The fracture morphology images observed by scanning electron microscopy revealed that both specimens fracture in ductile mode. Formation of dimples on the fracture surface could be recognized easily in 300 μm sample at higher magnification as compared to 100 μm sample.

Keywords: Thin sheet; tensile test; fracture behaviour; 304 stainless steel

Abstrak

Secara umumnya, spesimen dengan keratan rentas segi empat tepat biasanya digunakan untuk mengukur sifat tegangan sesuatu bahan. Walau bagaimanapun, saiz spesimen dan ketebalan boleh mempengaruhi keputusan. Dalam kajian ini, sifat tegangan dan kepatahan kepingan keluli tahan karat 304 yang sangat nipis telah disiasat. Ketebalan kepingan keluli tahan karat dikaji adalah 100 dan 300 mikron. Sampel tegangan telah dipotong kepada bentuk dumbbell berkeratan rentas segi empat tepat dengan lebar yang sama menurut ASTM E8. Hasil kajian menunjukkan bahawa kepingan keluli nipis 100 mikron mempamerkan kekuatan tegangan yang lebih tinggi dan tiada kesan alahan jelas berbanding kepingan 300 mikron. Imej-imej permukaan patah yang diperhatikan melalui mikroskopi imbasan elektron menunjukkan bahawa kedua-dua spesimen patah dalam mod mulur. Pembentukan lubang-lesung kecil di permukaan patah dapat dikesan dengan mudah pada sampel 300 mikron berbanding sampel 100 mikron pada pembesaran yang tinggi.

Kata kunci: Kepingan nipis; ujian tegangan; sifat kepatahan; Keluli tahan karat 304

1.0 INTRODUCTION

Stainless steel is widely used in many industries in line with technological developments. Properties of stainless steel make it suitable as components in many application such as chemical industries, automotive, electronic devices, medical applications etc. The ability of stainless steel to withstand high stress value and to operate at high temperatures allows it to become widely used. 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. The fact that material properties change with specimen size has been well known for several years [1-2].

Miniaturization technology has become more important in the fabrication of micro parts. When the size is decrease to the microscale, changes occur in the mechanical behaviour of materials and the effects is called size effect [3]. Effect of size is characterized by grain size, the dimension of the specimen and the size of the surface topography. Materials will demonstrate it mechanical properties such as modulus of elasticity, tensile strength, elongation, hardness and fatigue limit [4] and expose the elastic and non-elastic behaviours when forces is applied, thereby indicate its suitability for mechanical applications. 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.

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 very thin steel sheet. 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 mechanical properties of the micro-sized specimen for the production of tiny metal-based components.

In this study, mechanical properties i.e. Young's modulus, yield stress, ultimate tensile strength and elongation, and fracture behaviour of very thin 304 stainless steel sheet using rectangular cross-section specimens of two different thicknesses with same width according to ASTM E8 were investigated.

2.0 EXPERIMENTAL PROCEDURES

The material used in this study was very thin 304 stainless steel sheets. The thin sheet thickness was 100 and 300 µm. The chemical compositions of the material (wt. %) are listed in Table 1. Sample for tensile test were machined from 100 and 300 µm sheets into a dumbbell-shaped as shown in Figure 1 by using an electrical discharge machining (EDM) wire cut.

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

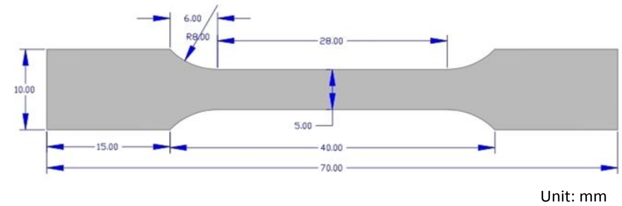
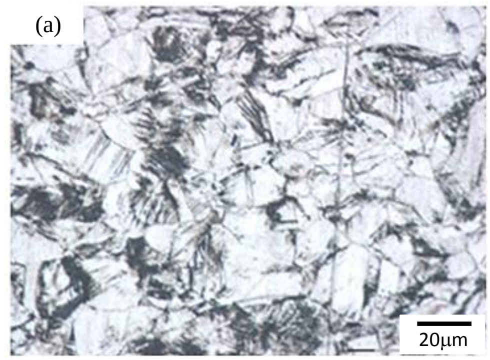
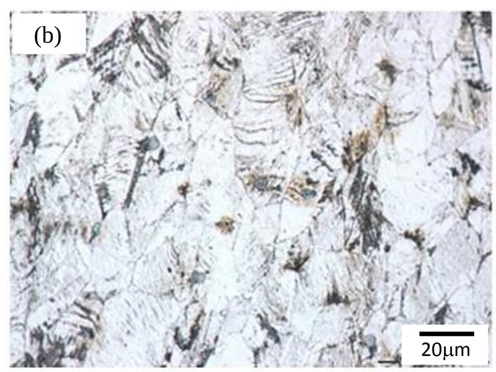


Figure 1 Tensile specimen size and configuration



(a) Microstructures of 304 stainless steel sheet of thickness 100 µm



(b) Microstructures of 304 stainless steel sheet of thickness 300 µm

Figure 2 Microstructures of 304 stainless steel sheet after annealed of thickness (a) 100 µm and (b) 300 µm

The width and length of gauge area were 5 and 28 mm, respectively. Tensile test was performed by using a zwick roell Z100 universal testing machine of 100kN capacity. Three samples indicated as A, B and C with a thickness of 100 and 300 µm were strained at a 1x10^{-3} sec-1 until fracture. The obtained stress-strain curves were then analysed to identify the young's modulus, yield stress, ultimate tensile strength and total elongation. Before the tensile test, all samples were process annealed at 700°C to relieve stresses due to cold working and EDM cutting process. Samples were ground using emery papers and polished using buff clothes with 1 μm diamond suspension before etched to reveal the microstructure. The microstructures of the 100 and 300 μm thin sheets are shown in Figure 2(a), Figure 2(b). The grain size of the samples were about 20-25 μm. All fracture surfaces of tensile samples were then observed using scanning electron microscope (SEM).

3.0 RESULTS AND DISCUSSION

3.1 Tensile Properties

The stress–strain curves for 100 and 300 μm of 304 stainless steel sheet are shown in Figure 3 and Figure 4, respectively. And the summary of the tensile properties are listed in Table 2 and Table 3, respectively. Three samples were tested for each thickness condition and labelled with A, B and C in each figure. The physical behaviour of the specimen was observed from initial loading until specimen failure. In the initial stage, both samples of different thickness loaded in the elastic range until reached the elastic limit. After the elastic limit, both samples behave differently. The 100 μm specimen did not exhibited a definite yield point, but rather shows a smooth stress-strain curve from the proportional limit to ultimate stress level as shown in Figure 3. For 100 μm specimen, the yield stress was evaluated based on the load at 0.2% strain. Beyond this point up to the maximum point, which is the ultimate tensile strength, the degree of strain hardening was very limited and the strain hardening finished at strain less than 2%. After the maximum point, the stress gradually decreased and specimen failed at about 9% strain elongation. Different tensile behaviour was observed for 300 μm specimen. The yield point can be observed clearly and directly from the stress-strain curve as shown in Figure 4.

However, this yield point (786 MPa) was much lower compared to the 0.2% yield stress of 100 μm specimen (1023 MPa). The upper yield point in 300 μm specimen was followed by a sudden reduction in the stress to the lower yield point. At this stage, the specimen continues to elongate without a significant change in the stress level up to about 5% strain. Load increment is then followed by increasing strain. The strain hardening in 300 μm specimen was more significant than that in 100 μm specimen.

Base on the results obtained, both 100 and 300 μm thickness samples exhibited different proportional limit stresses. The thinner sample shows higher proportional limit stress compared to thicker sample. It is suggested that the proportional limit of very thin sheet is thickness dependence for the thickness range tested. According to *Geers et al.* and *Shabani et al.*, dislocation slip in the grains is one of the dominant plastic deformation mechanisms for polycrystalline metals [5-6]. This means that in a very thin sample, dislocation can either be blocked by the grain boundary or glide out the surface of the sample. It is known that all grains in the interior of samples deform homogeneously. However, the grains close to the sample surface are less constrained by the surrounding grains, and less dislocation can accumulate in surface grains, as compared to interior grains. Therefore, for 100 μm thin sample, lower strain hardening and lower flow stress were observed after yielding. It is also reported that the elongation to failure and strain-hardening rate will increase with increasing thickness of specimen [7]. This is in-line with the finding in this study where thinner sample exhibited smaller elongation compared to thicker sample.

However, the thickness range tested did not influence the ultimate tensile strength of 304 stainless steel sheets where both samples showed identical value at about 1160 MPa as shown in Table 2 and Table 3. This result was similar to the result obtained by Yuan et al. where they investigated the influence of specimen thickness with rectangular cross-section on the tensile properties of structural steels. The small different in tensile strength may be due to the low ratio of the surface grain dimension to specimen thickness [8]. Another study by *Zhang et al.* and *Chen et al.* reported that when the grain size is approaching the specimen thickness, the grain function plays a very important role in influencing the mechanical properties of stainless steel [9-10].

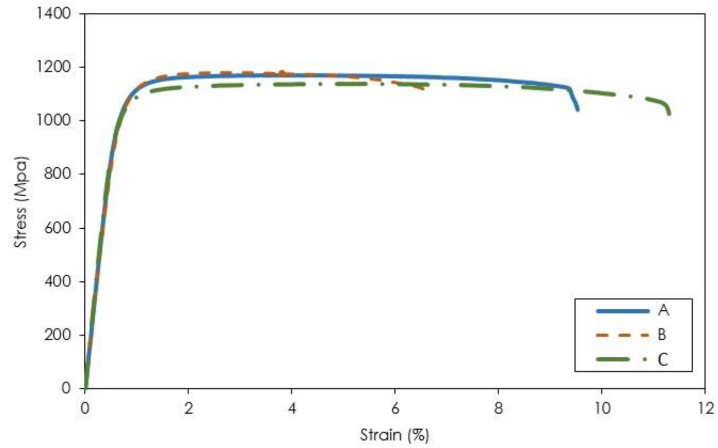


Figure 3 Stress-strain curves of 100 µm thickness 304 stainless steel sheet

Table 2 Tensile properties of 100 µm thickness 304 stainless steel sheet

Sample	Young's modulus (GPa)	0.2% Yield stress (MPa)	Ultimate tensile strength (MPa)	Elongation (%)
Sample A	205	1030	1170	9.5
Sample B	200	1020	1180	6.6
Sample C	202	1020	1140	11.3
Average	202.3	1023	1163	9.1

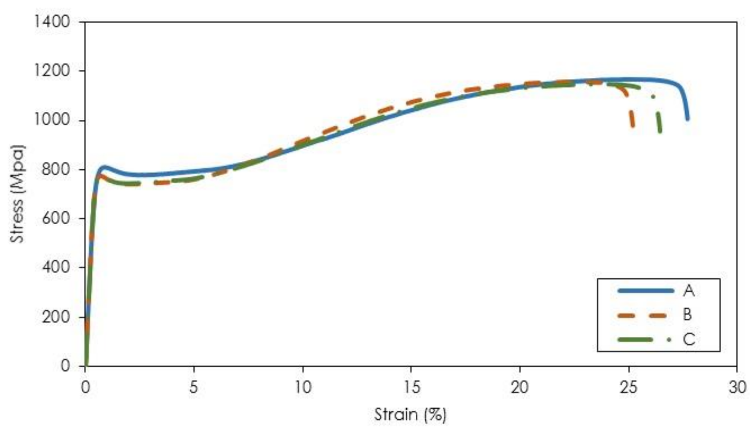


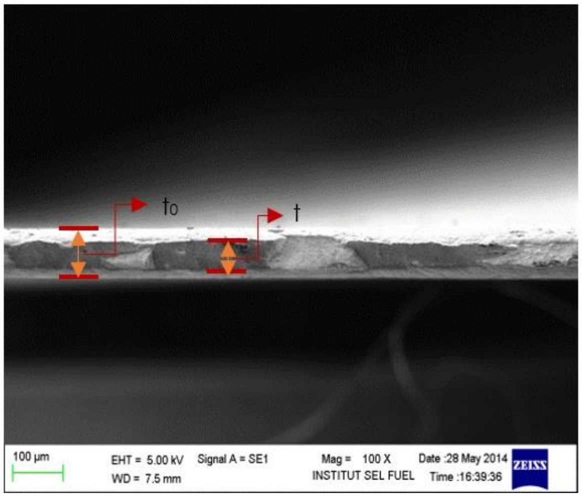
Figure 4 Stress-strain curves of 300 µm thickness 304 stainless steel sheet

Table 3 Tensile properties of 300 µm thickness 304 stainless steel sheet

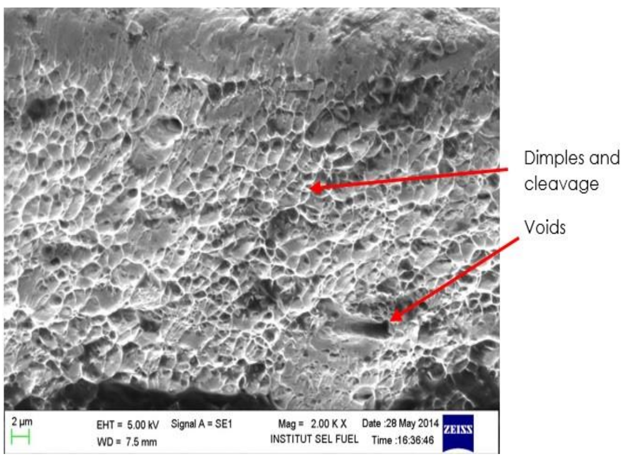
Sample	Young's modulus (GPa)	Upper yield stress (MPa)	Ultimate tensile strength (MPa)	Elongation (%)
Sample A	209	810	1170	27.5
Sample B	210	773	1160	25.4
Sample C	207	774	1150	26.4
Average	208.7	786	1160	26.4

3.2 Fracture Surface Analysis

Detailed fracture surface observation by scanning electron microscope are performed on the 100 and 300 µm thickness samples after tensile tests to analyse the failure processes, as shown in Figure 5 and Figure 6. A general phenomenon observed in both samples where necking occurs in thickness direction as shown in Figure 5 (a) and Figure 6 (a).

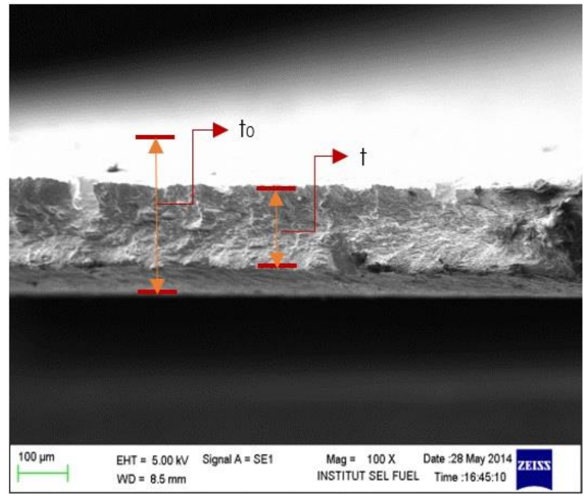


(a) 100 X magnification, t_0= specimen thickness before tensile test and t= specimen thickness after tensile test

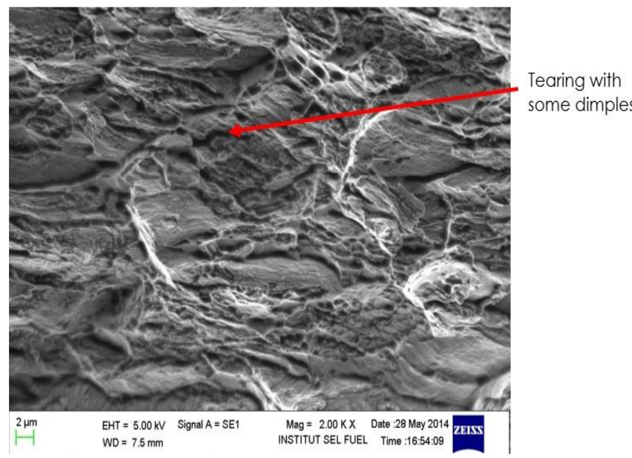


(b) 2000 X magnification

Figure 5 SEM fracture surface of tensile specimens of 100 µm thickness 304 stainless steel sheet with (a) 100 X magnification and (b) 2000 X magnification



(a) 100 X magnification, t1= specimen thickness before tensile test and t2= specimen thickness after tensile test



(b) 2000 X magnification

Figure 6 SEM fracture surface of tensile specimens of 300 µm thickness 304 stainless steel sheet with (a) 100 X magnification and (b) 2000 X magnification

However, the necking was more significant in thicker sample of 300 µm. The reduction in thickness direction can be seen from Figure 6 (a). Higher magnification observation showed small tension dimples, cleavage and voids on fracture surfaces of 100µm samples as shown in Figure 5 (b) and Figure 6 (b) showed small tearing with some dimples on fracture surfaces of 300µm samples. However, 100 µm samples fracture surface was more flat with the presence of cleavage pattern associated with dimples.

4.0 CONCLUSION

Tensile and fracture behaviour of very thin 304 stainless steel were investigated. The results are summarised as follows:

(a) Specimen thickness at the range of 100 to 300 µm influenced the mechanical properties of 304 stainless steel. Both samples showed differences in yield stress and elongation but Identical in its young's modulus and ultimate tensile strength. And the thinner the sample the lower the degree of strain hardening and ultimate tensile strength.

(b) Necking was found more significant in the thicker sample. The fracture behavior showed that reduction in the thickness direction was clearly seen in the 300 µm as compared to that in 100 µm sample. Fracture surface of 100 µm samples was more flat with the presence of cleavage pattern associated with dimples.

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