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Investigation on Mechanical Properties of 302 L Stainless Steel Sheets under constant amplitude loading

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Abstract:

In this study, the mechanical properties i.e., fatigue strength and fatigue crack growth (FCG) behaviour of 302 L stainless steel (S.S.) sheets with different thicknesses (0.05 mm, 0.1 mm and 1.5 mm) were investigated. The experimental investigation as well as fatigue life predication by using Walker model were performed. The FCG specimens were prepared according to the ASTM E647-08 standard. The results showed that S.S. sheet with 0.05 mm thickness exhibited higher tensile strength but limited ductility with no clear evidence of yielding as compared to 0.1 mm and 1.5 mm thickness.

Keywords: 302L Stainless steel; Fatigue life; Fatigue strength; Constant amplitude loading.

الخلاصة

في هذه الدراسة تمت دراسة الخواص الميكانيكية مثل مقاومة الكلال وظاهرة نمو شق الكلال لصفائح الفولاذ المقاوم للصدأ S.SL 302) بأسماك مختلفة (0.05 ملم، 0.1 مم و 1.5 ملم). وأجريت التجارب العملية بالإضافة الى تقدير حياة الكلال باستخدام نموذج ووكر. تم إعداد العينات وفقا لمعيار المواصفات الامريكية العالمية E647-08. وأظهرت النتائج أن عينات الفولاذ بسمك 0.05 ملم أظهرت مقاومة الشد أعلى ولكن ليونة محدودة مع عدم وجود دليل واضح على مقاومة الخضوع بالمقارنة مع العينات الفولاذية الأخرى بأسماك 0.1 ملم و 1.5 ملم.

الكلمات المفتاحية: 302 الفولاذ المقاوم للصدأ؛ عمر الكلال؛ عمر الكلال وثابت حمل السعة .

Introduction

Most of the mechanical properties of engineering materials available in the market are obtained through a bulk or standard big size samples and do not necessarily represent the actual properties of very thin and small size components. Therefore, it is essential to identify the tensile properties, fatigue and fatigue crack growth (FCG) behaviours of very small and thin samples. Stainless steel is a material broadly utilized as a part of the modern division in accordance with innovative improvements. Stainless steel material properties make it appropriate for parts focused, such as a high-push esteem and the capacity to work at high temperatures enables it to wind up noticeably generally utilized. The way that material properties change has been outstanding for quite a long while(Mussot-Hoinard *et.al.*, 2017; Nicholas *et.al.*, 2017). In latest years, the market request at the small-scale level, for example, stick connector, miniaturized scale screws, springs, IC attachments, smaller scale gears and small-scale shaft has expanded fundamentally because of the cutting back of the item. Small-scale parts have likewise been generally utilized as a part of numerous businesses including car, biomedical, aviation and hardware. Scaling down innovation has turned out to be more vital in the creation of miniaturized scale parts. When the span of decrease to the microscale changes in the mechanical properties and the effects of the alleged size effect (Neugebauer, 1960; Doerner *et.al.*, 1986).

The mechanical properties of stainless steel for example, modulus of flexibility, elasticity, elongation, hardness and fatigue limit that uncover the conduct of elastic and non-elastic when a power is connected in this way show its appropriateness for mechanical applications (Chan *et.al.,*2010). This work inspects the scenery of stainless steel S 302 L specimens, which influences the test technique. The experimentation was held out on examples having distinctive thicknesses to test ductile fracture conduct of separation thickness specimens (Jaswin, 2011). An analysis led on an example size of 0.1 mm and 0.3 mm miniaturized scale (Yuan *et.al.,*2012). This exploration includes the utilization of some hardware that universal testing machine (UTM), machine clean and examining electron microscopy. Prior to the tests are finished by utilizing the general testing machine was experiencing the procedure of heat treatment of extinguishing, it is proposed to restore the mechanical properties and microstructure of examples repairs (Zhang, 2006; Chen *et.al.,*2011). Dumbbell-molded specimens will be utilized for this frame effectively held by the machine, and the impact of crack is obviously noticeable on the specimens.

Methodology

This work investigates the effect of using different 302L stainless steel sheet thicknesses on the tensile strength, fatigue life and fatigue crack growth (FCG). Specimens with a Single Edge Crack Tension (SECT) were prepared by using an electrical discharge machining (EDM) wire cut according to the American society for testing and materials (ASTM) standard. The experimental procedures in this work divided in to several testes to obtain the effect of sheets' thickness on their mechanical properties. Then, most of micrograph is captured using using SEM machine in fuel cell laboratory (UKM) as shown in Fig 1. Fig. 2 shows the flow and steps the tests applied to achieve the paper objectives that will be details. The experimental procedures in this work divided in to several testes to obtain the effect of thickness on mechanical properties. The main tests conducted in the current work are tensile strength, fatigue life and FCG behavior testes.

Experimental tests

The material used in this study is as received according the ASTM A240. The chemical compositions of the material (wt.%) are listed in Table 1.These steel types are generally bellow about 0.25 % wt. C didn’t respond to martensitic heat treatment form, reinforcement achieved by cold effort. Significantly, these types of alloy are comparatively weak and soft, and then have excellent FT and ductility. Typical applications of ASTM A240 include automotive body parts and sheets used in pressure vessels, pipelines and tin cans (ASTM standard VI.03).

The tensile test specimens were machined from thin 302 L stainless steel sheets (0.05 mm, 0.1mm and 1.5 mm) into dumbbell – shaped as shown in Fig. 2. The test was achieved by using a (UTM Zwick Roell Z100) machine with 100 kN capacity as shown in Fig. 3 followed the ASTM E8 standard. Through this test, three samples from each thickness indicated as as-received sample’s (1.5mm, 0.1mm and 0.05mm) were strained at a $1x10^{-3}$ sec^{-1} until fracture at lab’s temperature. The obtained stress-strain curves were then analysed to identify the yield stress, ultimate tensile strength and total elongation.

Results and Discussions

The experimental investigation and prediction of fatigue crack growth (FCG) and fatigue strength under different load conditions were conducted. Initially, the material classification was extracted from a tensile and constant amplitude loading (CAL) fatigue test. The methodology started with several fatigue tests under CAL, which were performed under a similar limit condition. The fatigue life test procedure followed the ASTM E468 standard. Subsequently, the procedure of fatigue life test for (1.5 mm) specimen thickness is conducted under constant amplitude load with tension-tension fatigue test configuration with a capacity of 25 kN. The fatigue life test was run with Sinusoidal waveform (SWF) of loading with (load ratio $R = P_{min}/P_{max} = 0.1$), where P*min* is minimum service load load and P*max* is maximum service load, and *Freq= 20 HZ* at laboratory temperature.

The S-N curve achieved by ten samples, starts with 90 % until 50 % of ultimate tensile strength (UTS) when gets the endurance limit after 10^6 numbers of cycles. The predicted FCG between the experimental data and the Walker model for the representative case under CAL are shown in Fig.4. The accuracy of the model increases with an increasing number of cycles, because the Walker model was able to represent the FCG in early and final stage of the crack propagation. The deviation between the experimental result and prediction model was about 3 %. Meanwhile, the fatigue life test procedure for (0.1mm and 0.05mm) specimen thickness is also conducted under constant amplitude load with tension-tension fatigue test with a per-load (5 N) were run with an axial cyclic loading method with load ratio selected $R=0.1$ and fixed load *Freq around 0.1* Hz at a laboratory temperature. The S-N curve achieved by nine samples for 0.1mm thickness while seven samples for 0.05mm thickness, starts with 90 % until 50 % of UTS when get the endurance limit after 10^5 numbers of cycles. The predicted FCG between the experimental data and the Walker model for the representative case under CAL are shown in Fig.5 and 6 respectively. The accuracy of the model increases with an increasing number of cycles and it varies from thickness to thickness. However, it is possible to observe the number of cycles increase for 0.05mm thickness to reach the same crack length as the thickness of 0.1 mm. The deviation between the experimental result and prediction model was about 8 % and 11 % respectively. The differences in the predicted FCG are mainly due to the basic theoretical background for model used in this work.In addition to, the specimens containing defects arising from the manufacturing and servicing process. When the examined the experimental regression line through the polynomial equation, the correlation determination has been found the root square Error (R^2) were 0.9907, 0.9972 and 0.9871 respectively, This shows that the feed data (load ratio) be qualified and achieved smoothness and a concise notation.

Conclusions

In the present work, the experimental, simulation and prediction investigation of FCG have been addressed. The main objectives of this work the effect of thickness of very thin (50, 100 µm and 1.5 mm) 302L stainless steel sheet on mechanical properties, fatigue strength and FCG behaviour. Experimental findings of the FCG under constant amplitude loading and was compared with that of the proposed prediction model.

1. The results showed a good indication for the thin plate FCG and fatigue strength with a good matching between the experimental and modelling.

2. The deviation between the modelled life and the experimental result were 3 % ,8% and 11% respectively.
3. The main reason for the differences between the numbers of cycles is due to the theoretical background of the model.
4. This model is capable of representing all the factors affecting the fatigue life and for that reason their values are different from the experimental data.
5. Most of the fatigue models are based on integration of a crack growth rate equation in order to determine the fatigue life.

The future work wills focusing on introducing thermal coefficients onto the thin plates using Vickers hardness test to polishing surface specimen with different load indenter at different location points on the specimen for each thickness to obtaining the average Vickers hardness.

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Table. 1 Chemical composition (wt. %) of 302 L stainless steel sheet

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	V	Fe
0.028	0.369	1.44	0.032	0.0005	17.3	0.072	6.94	0.001	0.11	0.216	0.092	Bal.

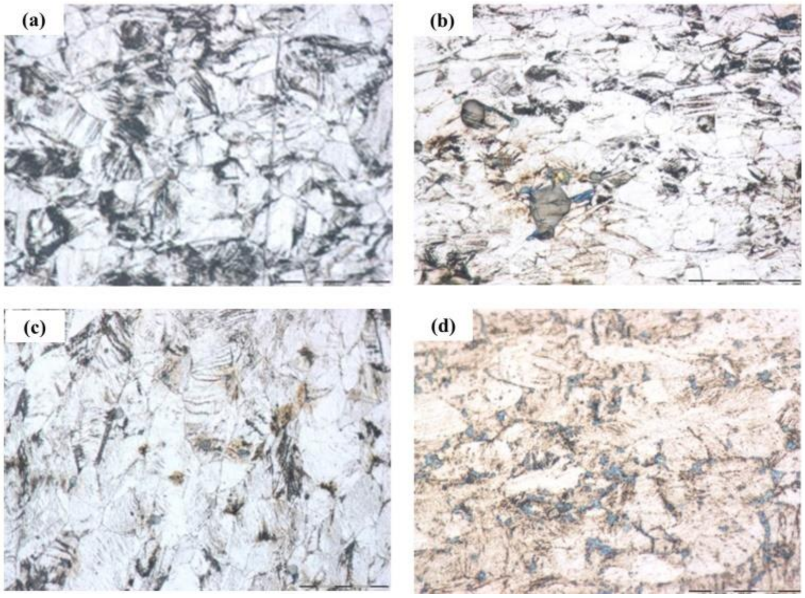

Fig. 1: SEM micro-strucyure of stainless steel 302L specimens

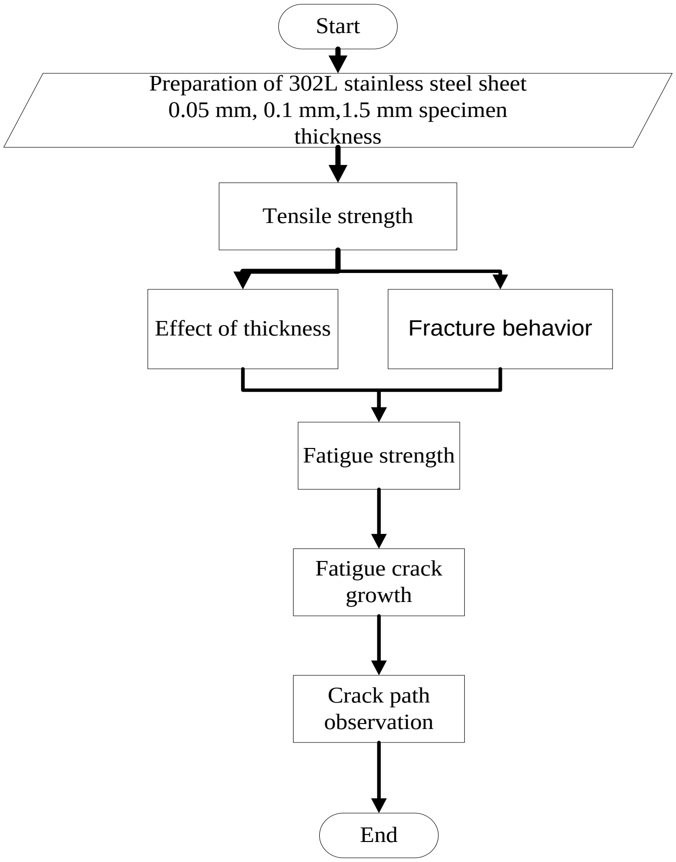

Fig. 2 Flow chart of research objectives

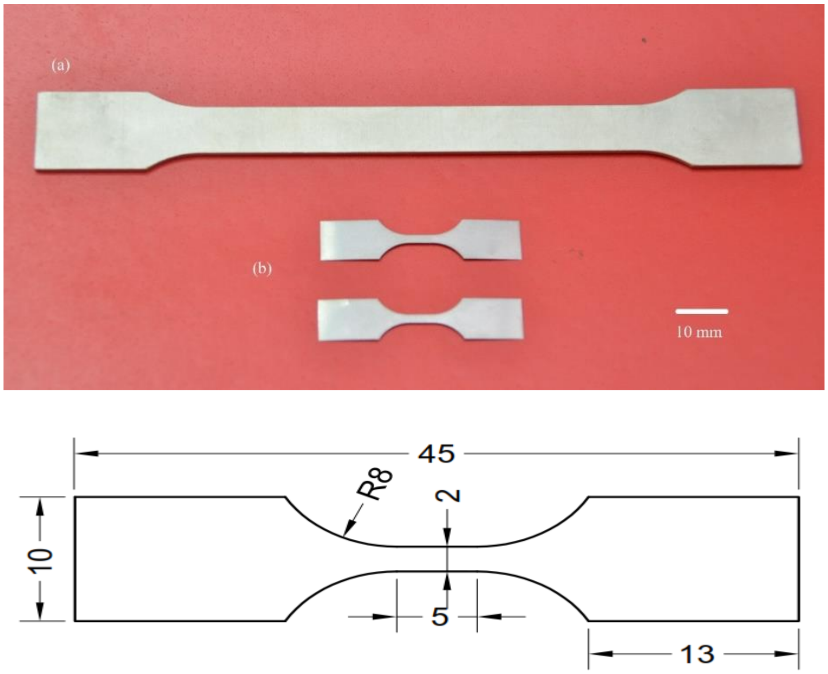

Fig. 2 Tensile test specimen for tensile test

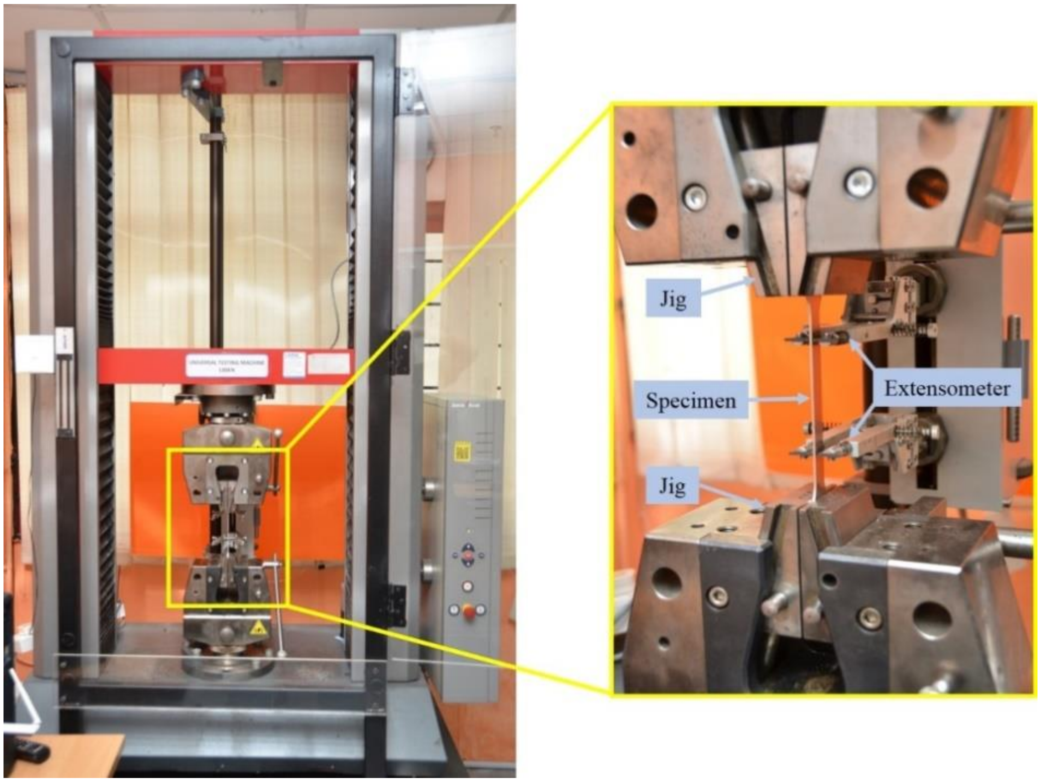

Fig. 3 UTM with a capacity of 100kN

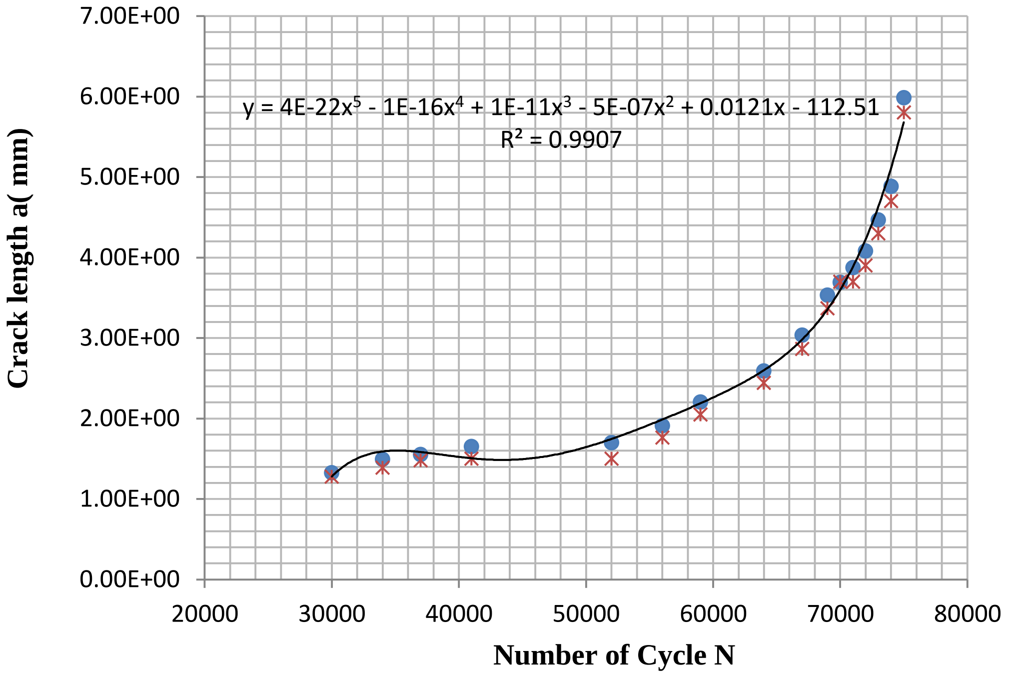

Fig. 4 a-N curve for 1.5 mm thickness

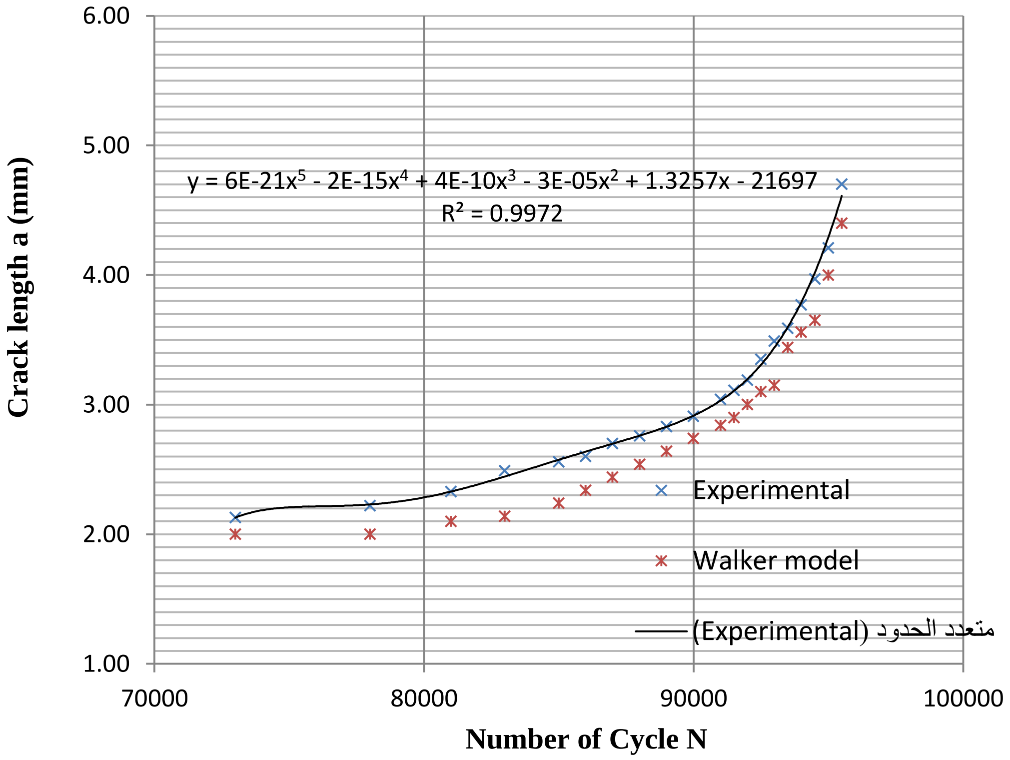

Fig. a-N Curve for 50 µm thickniss

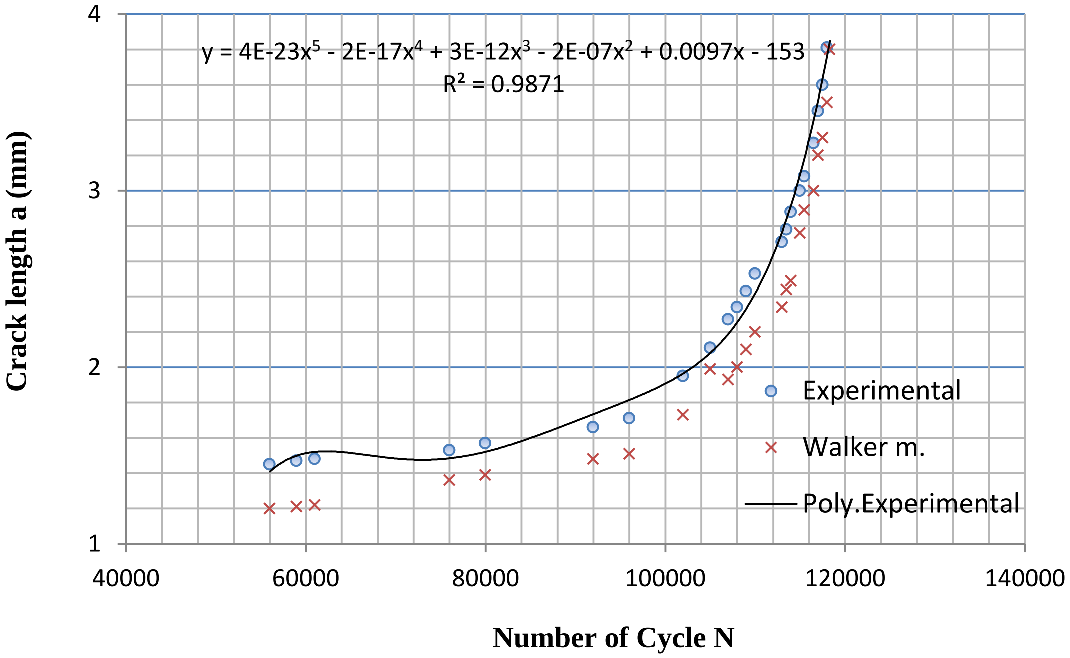

Fig. 6 a-N curve for 50 μm thickness