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PROCEEDING
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on Materials Engineering (ICME)
and
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FACULTY OF ENGINEERING UNIVERSITAS GADJAH MADA

INTERNATIONAL CONFERENCE ON MATERIALS ENGINEERING
AUN/SEED-NET REGIONAL CONFERENCE ON MATERIALS

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To Reduce the Fracture Mechanic at the Welding Spiral Pipe with Stress Relief Annealing

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Abstract: Submerged Arc Welding (SAW) is a welding process used for fabrication of pipes, for example spiral welded pipes. The technique can be operated automatically and has a high reliability in many various welding applications. Some factor affecting the strength of weld metals are heat input, current, and chemical composition of filler, flux, and base metal and also treatment after welded. The present investigation aims to study fracture mechanic after treatment with Stress Relief Annealing on submerged arc spiral welded steel pipes.Material used in this experiment was API 5L X-65 for spiral welded steel pipes. Welding was carried out using voltage of 35 volt, welding speed of 13,67 mm/s whereas post weld heat treatment temperature namely standard, 500°C, 600°C, 700°C to reduce fracture mechanic. Results show that, the annealing temperature while to height reducing fracture mechanic start with annealing temperature at 500°C, and decrease in 600°C, 700°C and without annealing.

Key Words: *SAW (Submerged Arc Welding), spiral pipes, heat treatment, fracture mechanic.*

1. INTRODUCTION

Steel pipe API 5L X65 is a pipe manufactured and produced based on API (American Petroleum Institute) standard. This pipe has carbon of 0,26 %; it is classified in low carbon. This type of pipe is usually manufactured by using Submerged Arc Welding (SAW). The problem commonly occurs in SAW (Submerged Arc Welding) API 5L X65 steel pipe is caused by the rate of high cooling in welding; it includes the emergence of residual tension and forming of microstructure in the form of martensit, residual austenite and carbide that declines toughness and strong of welding so that causes crack. If dynamical load occurs in welding connection, then crack will quickly creep and causes fracture. To solve this problem, treatment for stress relief annealing will be useful in impeding the rate of creeping in fatigue crack on the result of welding (SAW) API 5L X65 steel pipe.

2. REVIEW OF RELATED LITERATURE

2.1. Steel

Steel can be defined as a mixture from iron and carbon where carbon substance (C) is being the base of mixture. Besides, steel also contains other substances like sulfur (S), phosphor (P), silicon (Si) and manganese (Mg) in limited number.

According to Eunorom, steel is a compound from iron carbon and other substance where the carbon scarcely more than 2% (Vliet dan Both, 1987).

2.2. Steel Carbon

Steel carbon is compound between iron and carbon with little Si, Mn, P, S and Cu. The nature of carbon depends on carbon in the steel.

Steel carbon is classified based on carbon contain, strength and toughness. Steel carbon consists of three substance; they are:

a. Low steel carbon (C<0,2%)
b. Medium steel carbon (0,2%<C<0,5%)
c. High steel carbon (0,5%<C<1,7%)

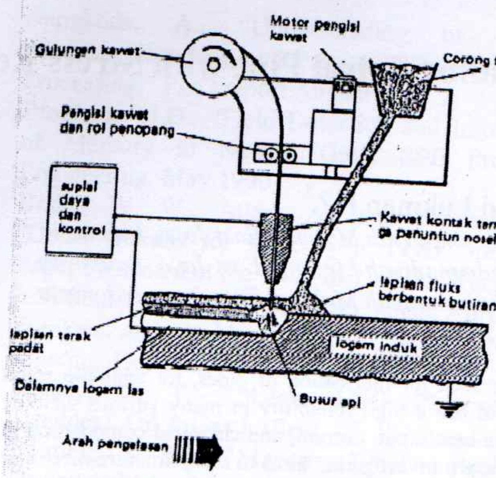
2.3. API 5L X 65 Steel Pipe

API 5L X65 steel pipe is a pipe manufactured and produced based on API (American Petrolium Instisute) standard. API 5L X65 steel pipe by specification of 5L is standardized specification by conference of making and distribution of line pipe for oil, water and gas by special usage.

Chemical composition of API 5L X65 steel pipe is C=0,1%, Mn=1,2%, Si=0,2%, P=0,015%, S=0,08%, Al=0,035%, Nb=0,03%, V=0,05% or C_{max}=0,26%, Mn_{max}=1,4%, P_{max}=0,03%, S_{max}=0,03%. API 5L X65 steel pipe has minimum mould strength of 448 Mpa and minimum tensile strength is 530 Mpa (Mittal Steel South Africa data, 1995).

2.4 SAW welding

SAW (Submerged Arc Welding) process is known by term of submerged arc welding. The basic principle of this welding uses electrical current to produce arc (arc) so that it can melt filler wire. In this SAW welding, filler wire is submerged in flux so that it can form enough strong of slag to protect filler wire to cool (Sonawan, 2003). SAW scheme is illustrated in Picture1.



Picture 1. SAW scheme

The example SAW welding application is pipe welding (whether it is from longitudinal or round pipe), industry of ship, welding for huge tank and surfacing and cladding.

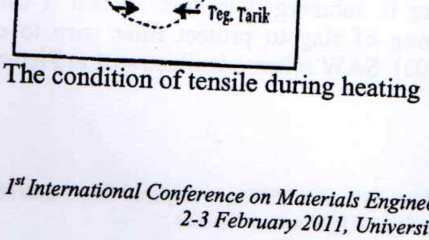
2.5. Structure of micro welding

The mechanical nature of welding connection that includes tensile strength, toughness and strength toward the rate of fatigue crack on steel depends on microstructure in welding. According to Abson and Pargeter (1986), welding microstruktur consists of two combination or more of the following phase:

1. Ferrite grain limitation formed on the temperature between 1000^0 up to 650^0C on austenite grain limitation.
2. Ferit Widmanstatten, formed on grain and grow in the middle of austenite grain in parallel plates. This ferrite formed in temperature interval of 750^0 up to 650^0C.
3. Acicular ferrite formed under 650^0C in austenite grain and formed (lath) that is arranged traverse like plait. (interlocking structure).
4. Bainit, formed on temperature of 500^0C in lath.
5. Microconstituent (martensit of residual carbide) in very little number.

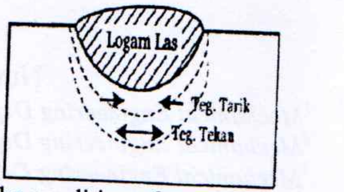
2.6. Residual Stress

During welding, an area under welding metal will in expansion, while under this try to hold it. The expansion area will have press strength will the under opposes with tensile strength, like illustrated in Picture 2.



Picture 2. The condition of tensile during heating

In contrast, during cooling process, the area under the welding metal experience tensile strength and area under it oppose by press like illustrated in Picture 3.



Picture 3. The condition of tensile during cooling

Tensile in welded plates will still exist up to base temperature. This tensile called as residual stress. If residual tensile is tensile strength, then it would be danger for welding construction, because if this tensile strength higher in such area (S_U), then it can cause crack up to the surface of welding metal.

2.7. Stress Relief Annealing

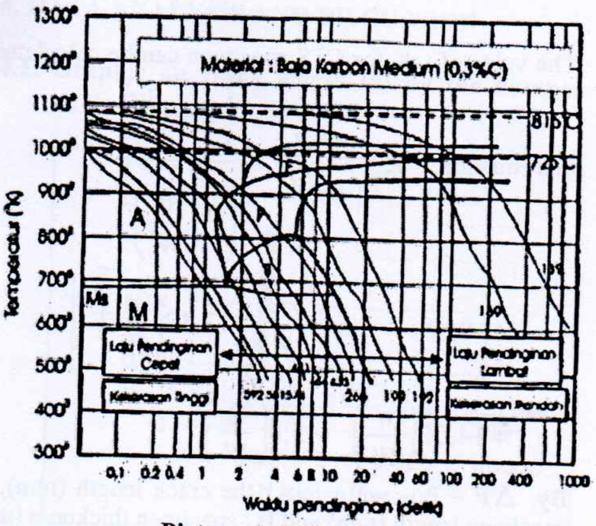
Stress relief process is a process of heat treatment after welding or post weld heat treatment (PWHT) that is aimed to eliminate residual tensile and microstructure in the form of martensit, residual austenite and carbide that is emerged in welding process. So that, it can increase toughness, strength, welding toughness and HAZ also increase endurance toward corrosion or even the rate of fatigue crack creeping.

Stress relief on steel usually conducted by heating in interval temperature of 450^0 up to 700°C, cooling time between 1 up to 3 hours and the rate of cooling is 1^0 up to 5^0C/minute (Radaj, 1992).

Annealing is aimed to soften steel so that it is easier to be manufactured by machine in cool condition, soften crystal and eliminate tensile. On this process, steel is heated slowly under the submerged temperature. Temperature depends on the type of steel in (0,5-2) hours, it is continued by cooling it in special chamber of this heat or by submerging workspace in lime powder, dust, fine sand, or other substance that can decelerate cooling process.

2.8. CCT Diagram

Commonly, microstructure on steel depends on the cooling speed from the temperature of austenite up to base temperature. Because of the change in this structure then the mechanical nature owned by material will change. The correlation between cooling speed and microstructure usually show in diagram that correlates temperature (T) and time (t), transformation temperature is CCT diagram (Continues Cooling Transformation). CCT diagram illustrated in Picture 4.



Picture 4. CCT Diagram

This diagram is not only observe the correlation between temperature and time, but also phases that possibly occurs in cooling case. A in phase diagram of Austenit, F = Ferrite, P = Perlit, B = Bainit, M = Martensit and Ms (Martensit start) = transformation line from martensit phase. While the numbers in every cooling line state the toughness number (Sonawan, 2003).

Microstructure in welding metal and HAZ are also influenced by cooling speed. It is caused by the cooling process of liquid metal (solidification) and transformation phase that is very sensitive toward cooling speed. As the example of cooling speed on steel is it is will cause the form of micro in the form of hard and brittle martensit (Subekhi, 2005).

2.9. Fatigue

Fatigue is creeping process because of periodical dynamical load. The main cause of fatigue failure is crack creeping. For component or structure by load that fluctuates during operation, fatigue failure is the main factor that should be considered to determine the limit of planning tensile because almost 90% of failure or concentration failure is always caused by repetition load or fatigue fracture (Broek, 1987).

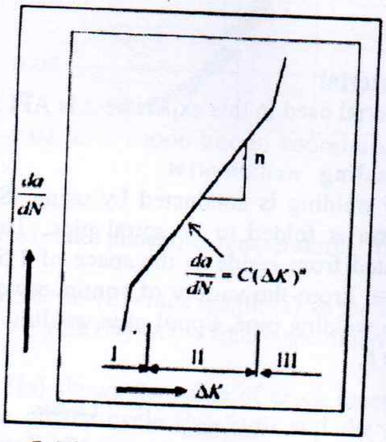
The main concept of fracture mechanic is a construction that is not should be 100% without defect but can have defect by defect time requirement (failure) that can be predicted fast.

Crack creeping on steel plates is influenced by many factors; they are plate thickness, plates material or product type, manufactured process, heat treatment, cool deformation and environment (Broek, 1987). Besides, crack creeping also influenced by residual tensile. Residual tensile on surface is driving tensile that increase endurance toward crack, while residual tensile inside is residual tensile strength that accelerate crack creeping.

Fatigue failure process can be divided into three steps; they are:

a. Oscillating deformation
b. Crack, whether it is on the surface or even defect on workspace.
c. Crack creeping that will cause fatigue crack.

The rate of crack creeping $\left(\frac{da}{dN}\right)$ as the function of ΔK is illustrated in Picture 5.



Picture 5. The characteristic of crack fatigue (Broek, 1987)

From Picture 2.5, it can be seen that the characteristic of crack fatigue can be divided into three areas:

a. Area I
   It is called as fatique treshold.
b. Area II
   In this area, the crack creeps linearly so that it is still considered in structure planning. In this area, there is Paris law (Broek, 1987) :

$$\frac{da}{dN} = C(\Delta K)^n$$

   Where n is slope from curve and C is coefficient.
c. Area III
   This area is ignored in structure planning because the rate of creeping very fast so that difficult to control. The number of ΔK is factor difference of intensity from maximum strains that can be wrote as follow:

$$\Delta K = K_{max} - K_{min}$$
$$= Y \Delta \sigma \sqrt{\pi \times a}$$
$$= Y(\sigma_{max} - \sigma_{min}) \sqrt{\pi \times a}$$

Where,

ΔK : is stress intensity factor range on the end of crack, a : the length of crack, σ = tensile and Y : is parameter that depends on (1) crack and (2) the size and the geometry of specimen.

3. METHODOLOGY

3.1. Research

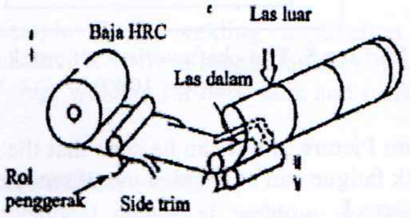
This research is experiment and literary study. It is by having experiment, observation and directly study on subject.

3.2. Material

Material used in this experiment is API 5L X65 steel.

3.3. Welding

The welding is conducted by using (SAW). Plate in coil form is folded to be spiral pipe. Then, welding is conducted from inside in the space of 1,5 meter outside the pipe. From the variety of continue welding model is outside welding pipe. Spiral pipe welding is illustrated in Picture 6.



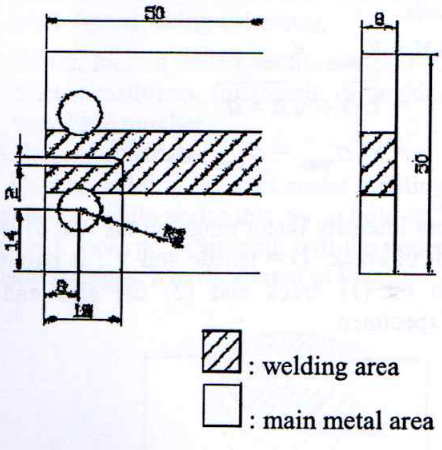
Picture 6. Spiral welding pipe

3.4. Stress Relief Annealing treatment

In this process, welding connection of API 5L X65 steel pipe is heated (stress relief) in heating chamber by temperature of 500 ^{0}C, 600 ^{0}C and 700 ^{0}C by 60 minutes. Then, it is cooled slowly (annealing) by air media.

3.5. Creeping testing of fatigue crack

Fatigue testing is conducted by tensile frequency of 5-15 Hz, tensile level of 40% from melted tensile and stress ratio 0,5. Specimen used here is based on ASTM E 647-95a in the form of compact tension specimen (CTS) like in the Picture 7.



Picture 7. Speciment by CTS form
(Standard ASTM E 647-95a)

The value of K for CTS specimen can be calculated by this equation:

$$K = \frac{\Delta P}{B\sqrt{W}} \times \frac{\left(2+\frac{a}{W}\right)}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}} \times \left[0,866 + 4,64\left(\frac{a}{W}\right) - 13,32\left(\frac{a}{W}\right)^2 + 14,72\left(\frac{a}{W}\right)^2 - 5,6\left(\frac{a}{W}\right)^4\right]$$

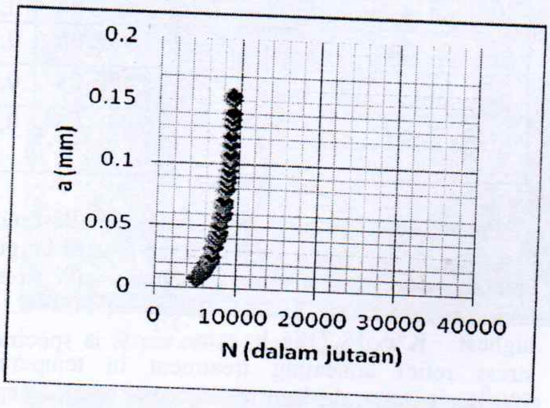
By, $\Delta P = P_{max} - P_{min}$, a : the crack length (mm), W : specimen length (mm) and B : specimen thickness (mm).

3.6. Fraktografi observation

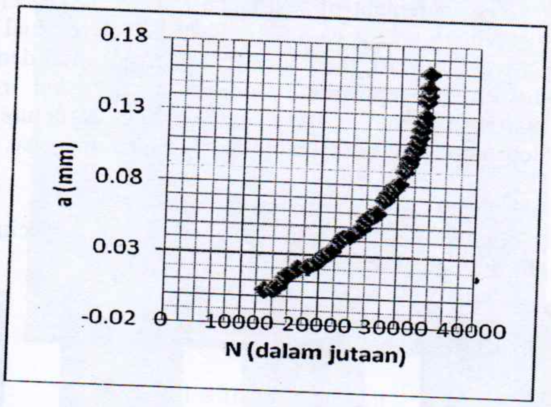
Fraktogarafi observation (fracture) of fatigue crack in welding area uses scanning electron microscope (SEM) that is equipped with energy dispersive X-ray (EDX) spectrometer.

4. DATA ANALYSIS AND DISCUSSION

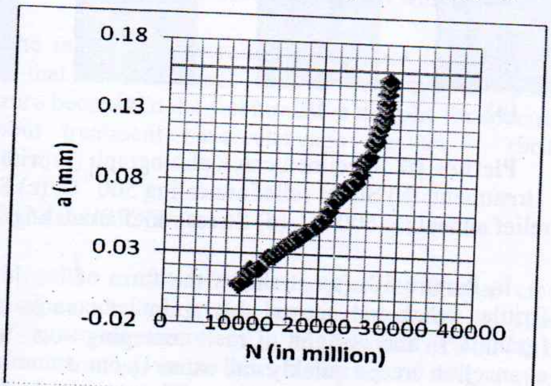
4.1. Graphic on crack length (a) by the number of cycle (N)



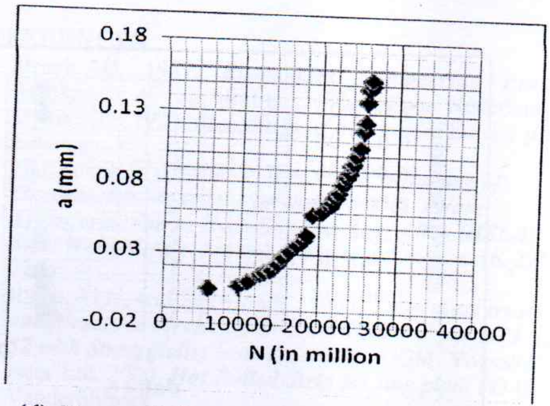
(a) without treatment



(b) Stress relief annealing temperature 500 ^{0}C



(c) Stress relief annealing temperature 600 ^{0}C



(d) Stress relief annealing temperatures 700 ^{0}C

Graphic 8. (a)-(d) crack length (a) vs the number of cycle (N) on the fourth specimen

Graphic 8(a) shows the value of crack creeping (a) it is 0,007 mm on the cycle (N) 5140 and the last crack creeping (a) is 0,154 mm o.n cycle (N) 9019.

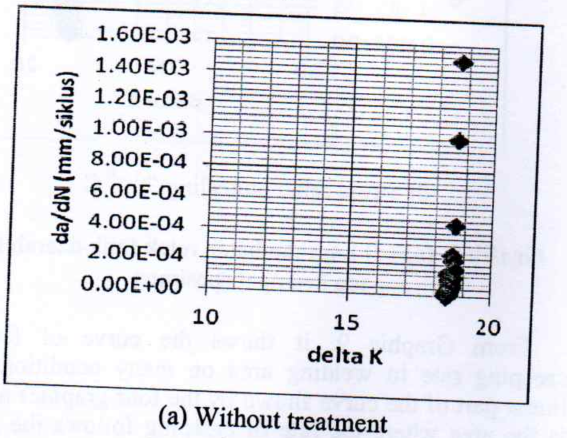
Graphic 8. (b) show the value of beginning creeping (a) it is 0,004 mm on cycle (N) 13032 and the last crack creeping (a) is 0,16 mm on cycle (N) 33660.

Graphic 8. (c) shows the value of beginning crack creeping (a) of 0,005 mm on cycle (N) 5729 and the last crack creeping (a) is 0,153 mm on cycle (N) 26279.

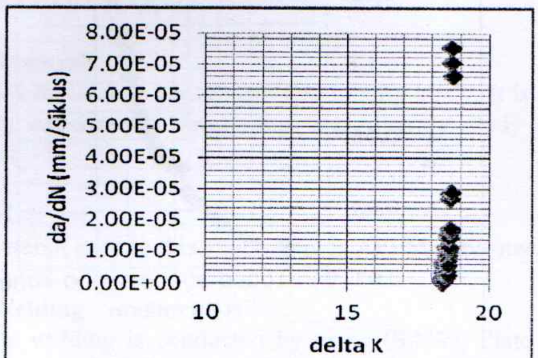
Graphic 8. (d) shows the value of beginning crack creeping (a) it is 0,008 mm on the cycle (N) 9712 and the last crack creeping (a) is 0,154 mm on the cycle (N) 28436.

From graphics 8. (a), (b), (c) and (d), it can be found the graphic by the most number of cycle (N) of 33660 on stress relief annealing treatment in temperature 500 ^{0}C. It means that on stress relief annealing treatment in 500 ^{0}C can give the best crack resistance than in the number of cycle without treatment of by stress relief annealing treatment in temperature 600 ^{0}C and 700 ^{0}C.

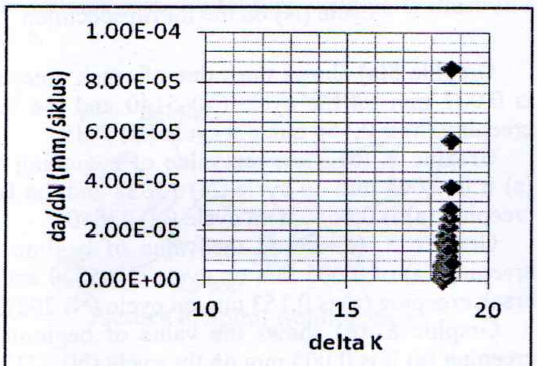
4.2. Graphic da/dN with K



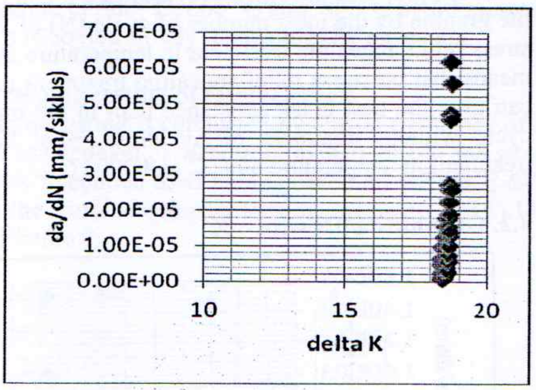
(a) Without treatment



(b) Stress relief annealing 500 ^{0}C



(c) Stress relief annealing 600°C



(d) Stress relief annealing 700 ^{0}C

Grafik 9. (a)-(d) Laju rambatan retak fatik daerah las pada keempat spesimen

From Graphic 9. it shows the curve of fatigue creeping rate in welding area on many conditions. In linear part of the curve shown by the four graphics above is the area where the rate of creeping follows the Paris law so that by making trendline linier on this area, it can be found exponential value of n and C constant for Paris law. The value of n and C from each is illustrated on the Table1.

Table 1. Paris Constant from the four specimens

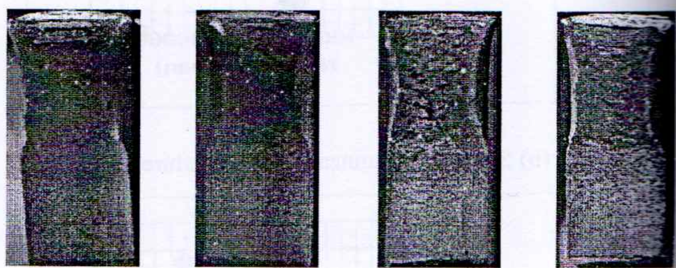
SPECIMEN	C mm/siklus	n
Without treatment	2,62E-04	0,2739
Stress relief annealing 500 ^{0}C	2,96E-05	0,2590
Stress relief annealing 600 ^{0}C	8,49E-05	0,2846
Stress relief annealing 700 ^{0}C	6,09E-05	0,2718

From Table 1. can be seen that the smallest number of C means the increment of resistance toward fatigue crack creeping rate occurs in the specimen with stress relief annealing treatment in temperature of 500 ^{0}C. For the highest K is 18,7186 kg.mm $^{-3/2}$; it is specimen with stress relief annealing treatment in temperature of 500 ^{0}C; it shows the best resistance of crack creeping rate by accelerated value of smallest n 0,259.

The increment of resistance toward fatigue creeping on welding area is caused by liberation of residual tensile on welding area, the decrement of dislocation density or dislocation reposition on low energy and residual martensit that brittle on welding structure with decomposition so that welding toughness increase.

4.3. Fracture macro Photograph

Fracture macro photograph from four specimens is illustrated in the Picture 10.



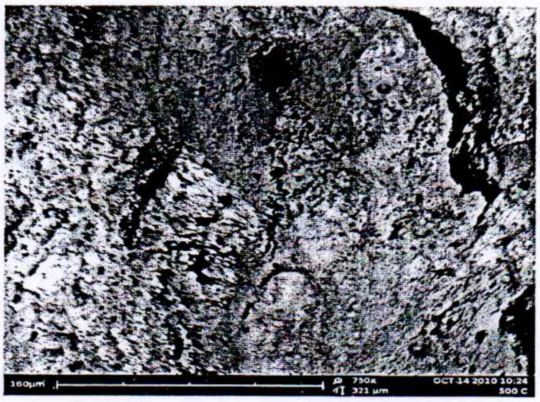
(a) (b) (c) (d)

Picture 10. Specimen crack photograph (a) without treatment, (b) Stress relief annealing 500 ^{0}C, (c) Stress relief annealing 600 ^{0}C, (d) Stress relief annealing 700 ^{0}C

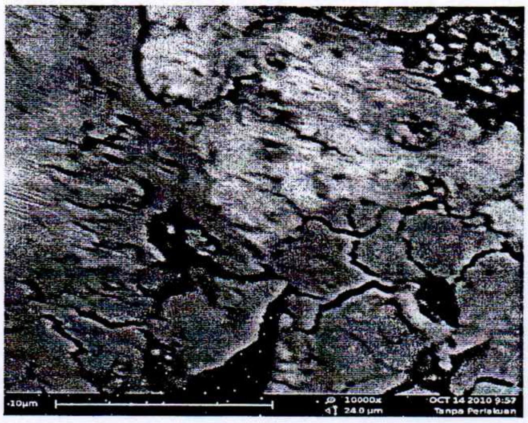
In Picture 10. (a), it shows the form of brittle crack. Brittle crack is shown by granular crack surface (granular) and bright. Crack creeping on welding connection creeps quickly and cause fracture.

In the Picture 10.(b), (c) and (d), it shows the form of fracture in tough; it means the influence of stress relief annealing treatment toward welding connection is visible. Toughness fracture gives fibrous characteristic (fibrous) and dark (dull). Tough fracture is preferred because tough material commonly stronger and give caution first before defection.

4.4. Fracture fotograph (Fraktogtafi)



a. Stress relief annealing 500 ^{0}C,



b. (a) without treatment

Picture 11. Fracture Photograph with SEM

The result of observation for surface fracture as the seen that the treatment with 500C have the ductile fracture because in the fracture have dimple, for specimen without treatment have cleavage fracture (brittle fracture)

5. CONCLUSION

From the result of this experiment, fatigue crack creeping conducted, it can be concluded that by stress relief annealing treatment in temperature of 500 ^{0}C by 60 minutes can give the best resistance of fatigue crack creeping rate on welding area.

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