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THEORITICAL ESTIMATION OF STRENGTH OF OVER LAP JOINING OF SHEETS

Ahmed M. Almukhtar
Manufacturing Operation Dept.
Al-Khwarizmy Collage of Engineering
Univercity of Baghdad

ABSTRACT

One of the main purposes of this study is to understande the reason of determining the standared of the parameters for overlap spot welding test, which is based on the thickness and overlap distances. The overlap joint is the most convential joining for the spot and riveting joint. The analysis of riveted and welded connection involves so many indeterminate factors that an exact solution is impossible. Nevertheless, by making certain simplifying assumption The most significant of these assumptions is that when the applied load passes through the centroid of the spotted region and the rotation angle will be small. By using the classical fracture theory, Misses and bending beam theory. The result which explain the behavior of the junction to the applied load, and to the rotational angle which depend on the yield strength of the base metal and on the maximum load of the welded joint. The different parameters were affected on the rotation of the welded joint and fracture load. Here, ''failure'' of the test sample is defined as the ''fracture initiation'', which corresponds to the peak load as discussed earlier.

Two theories were applied with simple assumptions which used to reach the final formula in which suitable for lap welded joint. Also the mechanism of fracture and initation of crack have been examined.

الخلاصة

ان احد الاهداف الاساسية من هذه الدراسة هو فهم الاسباب من تحديد المتغيرات والابعاد الخاصة لقطعة اللحام التراكبية الشكل بالاستناد على سمك ومسافة التراكب للعينات. تعتبر الاشكال التراكبيه من المقاطع المألوفة في عمليات اللحام النقطي وعمليات البرشمة. التحليل النظري للاحمال المسلطة على القطع المبرشمة والملحومة تتضمن متغيرات غير محددة والتي يكون معها التحليل غير ممكن الابعمل بعض الفرضيات التي تبسط التحليل. في هذا البحث اعتمد افتراض الحمل المسلط واقع على محور نقطة اللحام وافتراض ان مقدار زاوية الدوران تكون قليلة. من خلال استعمال فرضية فون- ميسس و فرضية العتبة المنحنية تم الحصول على نتائج مبسطة توضح سلوك القطعة التراكبية وكذلك زاوية الالتواء نسبة الى الحمل المسلط و مقاومة الخضوع للقطعة المعدنية نفسها . تم وضع اشكال بيانية تبين تأثير المتغيرات المختلفة على زاوية الالتواء ودوران الوصلة وكذلك على حمل الكسر. تم توضيح ميكانيكية الكسر وكيفية بداية نشو التشقق. تم تطبيق الفرضيتين اعلاه للوصول الى علاقة عامة للوصلات الملحومة تراكبيا . ان استخدام مصطلح الفشل في هذا

البحث للعينات تشير الى بداية نشوء الكسر والذي يشير الى الحمل الاقصى الذي تتحمله منطقة اللحام قبل ان تتكسر بشكل كلي.

KEY WORDS

Lap joint. Spot welding. Rotation angle. Strength of joint. Failure of spot welds.

INTRODUCTION

Steel sheet in structural applications is one of the fastest growing segments for stainless steel. In the US market some 20 percent of all stainless steel is estimated to be used in this market segment. A good example of a growing sub-segment is the transport sector, e.g. busses and trains.(Hans Norberge.2004).

To further increase the penetration of this market we need to develop our understanding of the Mechanical properties of stainless steel and stainless steel structural elements. This means among other things a need to develop joining techniques suitable for these applications, establish structural element behavior under static and dynamic loads, and develop design guides. The ultimate tensile strength of specimen and manner of failure whether by shear or tear and nature of fracture, ductile or brittle. etc.

Hans Nordberg . (2002). at the swidish institute for metals Reaserch have studied the spot welded joint particular with referances to fatigue behaviour. Three different joint configarations (test speciman type) have been studied. **Fig.(1).**

Specimence Type (a) is the standerad single over lap joint that which highly used for the spot welded joint the geometry of specimance of lap was approximated as closly as possible to have pure shear mode on the joint. To increase the stiffness and reduce transverse forces speciman Type (e) was designed with stiffining flanges. For these two type the load transfer is basically shear but with an increasing transverse force for speciman Type (a) . to investigate the strength in pure tension transverse the sheets speciman type peel joint may be used.

Some basic types of lap joints are schematically shown in **Fig.(1)**. In this figure the joining technique is assumed to be adhesive bonding but could as well be spot welding, laser welding, clinching. riveting or some combination of these. The simple lap joint with some modification as in **Fig. (1f)** is for obvious reason the most widely used. This specimance the spot weld was submited to combined shear stresses and certain amount of through thickness tensile stresses.

Lugecheider . (1977) present a study show that in many cases. the AWS standardized model based on simple shear stress produces higher than actual tensile stength values for the brazed joint.

GENERAL CONSIDERATION

A failure of spot weld has been related to many parameters, e.g., residual stress, material in homogeneity. Welding parameters, thickness, nugget size, and material properties of the heat affected zone and base metal. Attempts to include all these parameters in a failure criterion would require substantial analytical. This stresses can then be related to the far field applied load and subsequently failure load or ultimate strength of the spot weld sample. For lap-shear samples, since the failure is predominant by unit-axial tensile load and the weld nugget is circular, a harmonic tensile stress distribution around the weld nugget,

The distribution of the stress can be writing as (Yuh Chao.2003):

$$\sigma(\theta) = \sigma_{\max} \cos\theta \tag{1}$$

Where θ =-90 deg to 90 deg and $\sigma_{\max}$ is the maximum tensile stress. Due to symmetry there is another similar stress distribution in θ =90 deg to 270 deg with $\sigma_{\max}\, at\, \theta = 180$ deg. acting on the other piece of the coupon. Equilibrium Condition requires that:

$$p=\int_{-\pi/2}^{\pi/2}\sigma(\theta).\frac{d}{2}.t.\cos\theta.d\theta=\frac{\pi}{4}td\sigma_{\max}=0.785td\sigma_{\max} \qquad (2)$$

Where:

P is the applied tensile load at far field. Equation (2) relates the local maximum stress to the far field load. At the initiation of fracture, Equation (2) becomes:

$$p_f=0.785td\sigma_f \qquad (3)$$

Where t: thickness of the base metal sheet or one-half thickness of the weld nugget.

D: Nugget weld diameter.

P_f The failure load (strength of the sample).

σ_f The fracture stress of material. Here. "failure" of the test sample is defined as the "fracture initiation". which corresponds to the peak load as discussed earlier.

In most cases the stress situation is so complicated that it can be calculated only by an equivalent stress and know theories of elasticity and plasticity (Lugschelder et al.1977). The tensile stress within the joint and weld nugget can not be neglected due to developing the twisting angle, it which increases by increasing the load. It can be have small amount. However, depending on the thickness of the sheet and overlap distance. Moreover depends on the position of weld nugget.

The classical fracture theory it can used to describe the fracture relation with the joint parameters:

Mises Criteria

$$\sigma^2_e=\sigma^2_v=\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2\right] \qquad (5)$$

The equivalent stress σ_e ... is calculated on the principal stresses σ_1, σ_2 and σ_3 by this hypothesis .

In simple tension σ_3 neglected because it is very small in single lap joint.

according to **Fig.(2A)**. the equivalent stress can be calculated based on Mises hypotheses:

$$2\sigma^2_e=(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2$$

$$\sigma_3=0$$

(It can be assumed that stress equal to the load because the smaller area of weld nugget), therfore:

$$\sigma_1=p_1\cos\theta$$

$$\sigma_2=p_2\cos\lambda=p_2.\cos(90-\theta)$$

as shown from **Fig.**(2A).

$\sigma_1=\tau$ (parallel to the weld nugget) , $\sigma_2=\sigma$

$$2\sigma_e^2=\sigma_1^2-2\sigma_1.\sigma_2+\sigma_2^2+\sigma_2^2+\sigma_1^2$$

$$2\sigma_e^2=\sigma_f^2.\cos^2\theta-2\sigma_f^2\cos\theta.\sin\theta+\sigma_f^2\sin^2\theta+\sigma_f^2\sin^2\theta+\sigma_f^2.\cos^2\theta$$

$$\frac{\sigma_e^2}{\sigma_f^2}=\cos^2\theta-\cos\theta.\sin\theta+\sin^2\theta$$

$$\frac{\sigma_e}{\sigma_f}=\sqrt{1-\sin\theta.\cos\theta}$$

$$\sigma_e=\sigma_v=\sigma_f.\sqrt{1-\sin\theta.\cos\theta} \qquad .(6)$$

This relation was found to estimate the fracture load and equivellant stresses for the overlapped joint of the brazed welded (Lugscheider et al. 1977). From the systematic testing and with some hypothesis it can be calculated for the single overlapped spot welded joint as shown:

$$\sigma_e = \sigma_s = \sigma_f \sqrt{1-\sin\theta.\cos\theta}$$

$$p_f = 0.785 t d \sigma_f \qquad (3)$$

Sub the Equ. (3) in the Mises creteria Equ.(6) . The relation that appear the effect of the sheet thickness and the weld nugget diameter with the rotation angle.

$$\sigma_e = \frac{p_f}{0.785td}\sqrt{1-\sin\vartheta.\cos\theta}$$

In case of small rotation angle , it can be assummed that the above relation by simplified as follow:

$$\sigma_e = \frac{p_f}{0.785td}\sqrt{1-\sin\theta} \qquad (7)$$

$$p_f = \frac{0.785td\sigma_e}{\sqrt{1-\sin\theta}} \qquad (8)$$

This relation had been found in this work for the first time to estimate the fracture load for the spot welded joint.

Therotical Calculation Of The Rotational Joint Angle

To evaluate the effect of different joint parametars on joint rotation and the resulting developmant of oppenenig mode tensile (or peel stresses) , a simple analytical model using beam bending theory have been developed. **Fig. (2A)**

$$\sum T = J\theta, \Rightarrow \theta = \frac{M}{J} \Rightarrow \theta = \frac{p\frac{(h+t)}{2}}{\frac{bh^3}{12}}, T = p\frac{(h+t)}{2},$$

$$\theta = 6*\frac{p(h+t)}{bh^3}, \theta = \frac{TL}{GJ} \Rightarrow \theta = 6*\frac{p(h+t)}{Gbh^3}*a$$

$$\sigma_1 = \sigma_t = \sigma_f.\cos\theta \qquad .(a)$$

$$\sigma_n = \sigma_2 = \sigma_f \sin\theta \qquad .(b)$$

$$\sigma_1 = \sigma_{peel} = \sigma_{moment} \qquad (c)$$

$$\theta_1 = \theta_{peel}, \theta_2 = \theta_{moment}. \qquad (d)$$

$$\theta_2 = \theta_{moment} = 6*\frac{p(h+t)}{bh^3}$$

$$\theta_1 = \theta_{peel} = \frac{TL}{GJ} = \frac{P*a}{\frac{bh^3}{12}*G}, \Rightarrow \theta = \frac{p*\theta}{\frac{bh^3}{12}*G}*a*a$$

$$\theta_{trav} = traverseload = \frac{6*p*a^2}{bh^3*G}*\theta$$

$$\theta_{total} = \theta_{net} = \theta_m - \theta_{peel} \Rightarrow \theta = 6*\frac{p(h+t)*a}{Gbh^3} - \frac{6*p*\theta*a^2}{Gbh^3}$$

Thus the net rotation angle:

$$\theta = \frac{h+t}{a*\left[1+\frac{Gbh^3}{6*p*a^2}\right]} \qquad (9)$$

Where:

θ: The rotation of the joint. (deg.)

h: Sheet thickness.(mm.)

t: Sheet distances between two sheet.(interfacing dist.). it can be assumed 0 for spot welded joint.

a: Joint length to the center of applied load point.(mm.)

G: Shear modulus of the material (N/mm^2).

b: Overlap length (mm).

P:Load (N).

As shown at the **Fig. (2B)**

Weld Nugget Indentation

Its into the base metal is ordinary permitted to vary from 20-80% of the thickness of sheet. Therfore it can be compensating by the weld nugget indentation for the sheet distance in Eq. (9).

Where:

Sheet indentation= 0.6 D.

D: Weld nugget diameter (mm).

Substituting in Eg. 9

$$\theta = \frac{h+0.6D}{a*\left[1+\frac{Gbh^3}{6*p*a^2}\right]} \qquad (10)$$

RESULT AND DESCUUSION

From the experimantal tests in the previous workes (Lugschelder et al.1977) in which confirm with the theoritical estimation for the deformation behaviour , the eccenrticity of the load path **Fig.(2a)** resulte in a rotation of the joint during loading , this will resulte in a tensile load .The behavior of the effect rotation angle with the tensile loads have been conducted in this reaserch. Although the tensile load (oppening mode) have the little effect in compared with shear load.

Since $P_{peel} = P*\theta$ .The traverse load (tensile load) increase with increasing load (shear stress) and rotation of joint.

FAILUAR MECHANISM FOR LAP-SHEAR SAMPLE

The interfacial fracture usually occour in lap shear specimens at the interfacing surface due to the low twisting moment and due to the shear stresses effect. Therefore the joint of stainless have a little amount of twisting angle.

Observation during tensile test of lap-shear samples reveals the failure process as schematically demon-started in **Fig. (2A)**. As the sample has been pull initially, the weld nugget experiences rotation. In the advanced stages of pullout the pieces, the material surrounding the weld nugget is subjects to predominately-tensile load and deformation near the nugget is similar to rigid button. When the load increases, localized necking of the sheet metal occurs at the two pieces, at locations near the juncture of the nugget and the base metal. Note that these two points are on the two different pieces of the coupons. Fracture then initiates at one of these two points. When the ductility of the sheet material is reach, eventually pullout failure of the weld occurs as the initial crack grows around the circumference of the weld nugget. **Fig. (3)** Show the surface of a test sample that which tested from systematic tensile test.

The dark hairline at the lower circumference of the nugget is the crack indicating the fracture initiation site. As can be seen from the below **Figs. (3, 4)**. The fracture initiation when some crack propagation. It usually observes in the periphery of the weld nugget.

The simple tension test were used for the spot weld specimance and the fracture zone have been observed.

This result that found from systematic macrostractural testing of the weld nugget reigon. And that which agreed with the described by (Yah Chao.2003), Journal of Engineering Material and Technology.

Effect Of Sheet Thickness

The effect of sheet thickness and length (slenderness) is more complex as Shown in **Fig. (5)**, for sheet thickness up to 2 mm the rotation increases with increasing sheet thickness and decreasing slenderness (sheet length). The increasing of sheet thickness above the 2 mm will increase the stiffness of joint and will increasing the shear stresses and reduces of peel stresses that which causes of the rotation around the tension axis.

Since lap joint strength is highly influenced by the transverse peel forces, this observation can explain why bonded thin high strength sheet joints can have a higher strength than thicker sheet joints. To reduce the rotation for a given sheet thickness and load, the stiffness can be increase with corrugation or with flanges . The increases of sheet length will reduce the rotation because of increase the ovelapped distance that required to rotate. Morover the effect of load can be shown from **Fig.(5)**. The increasing load, the rotation will decrease.

Effect of Applied Load

It can be seen that the fracture load (as defined as the peak load that causes the initiate the fracture load) will increase with increasing of rotation angle and up to 1.5 deg. **Fig.(6)**. The increase of rotation will developed the peel or tension stresses beside of the shear stresses. So it can be observed that increase the angle above the 1.5 deg. will decrease the fracture load that required to cause the fracture initiation.

From this resulte the behaviour of tensile test resulte (load-extension chart), it can be explained the load increase with the continous of pullout and then strat to dropped until rach to fracture.

Moreover the thickness will increase the fracture load up to the certain limit and then dropped above the 2mm. it can be shown that the similar behavior between the fracture load from the misses criteria Equ.(8) and the bending beam theory Equ.(9). This phenomenon agrees with that concluded by Lugschelder et al. (1977)

Effect of Weld Indentation and Overlapped

Fig.(7) shows that increasing of overlap will reduces the rotation becuase the increase the fastening of joint. The increases the weld joint fastening will reduces the rotation and decrease the peel stresses.

From **Fig. (8)** It can be observed that the increase of rotation angles with increase the weld indentation. The weld indentation will increase the joint fastening over the overlap area . The shear effect will reduce with increase the peeling forces (traverses load) in which increase the rotation of joint to the tension direction. The weld nugget indentation and the nugget penetration increase the joint strength of weld nugget.

The weld nugget indentation correlates with the other parameter such as the weld current and duration. Because the correlation between these two parameters and the weld nugget size (weld indentation). The weld nugget size and indentation increased with increasing of the weld current and time.

Effect of Sheet Thickness and the Load

From Fig. (9) It can be shown that the increases of the sheet thickness will increase the fracture load (peak load to initiate the fracture) of the spot welds nugget. Moreover, the increase the angle will reduce the fracture load. The traverse load increase with increase the rotation angle as shown in Fig. (2)

CONCLUSIONS

1- Lap shears specimens for steel have a little amount of twisting angle and have high strength
2- The fracture will be an interfacial fracture at the faying surface.
3- Pullout failure of the weld occurs as the initial crack grows around the circumference of the weld nugget. These cracks extend to the entire of nugget and branches until fracture. The initial crack started at the outer shell of nugget, which highly stressed from the welding processes.
4- The sheet thickness and length (slenderness) is more complex to effect on the fracture load. For sheet thickness up to 2 mm, the rotation increases with increasing sheet thickness and decreasing slenderness (sheet length).
5- The fracture load increase with increasing of rotation angle and up to 1.5 deg and then start to drope. Moreover the thickness increases the fracture load up to the certain limit and then dropped above the 2mm. The increase weld nugget diameter also increases the fracture load.
6- The weld nugget indentation affect on the rotation of joint.

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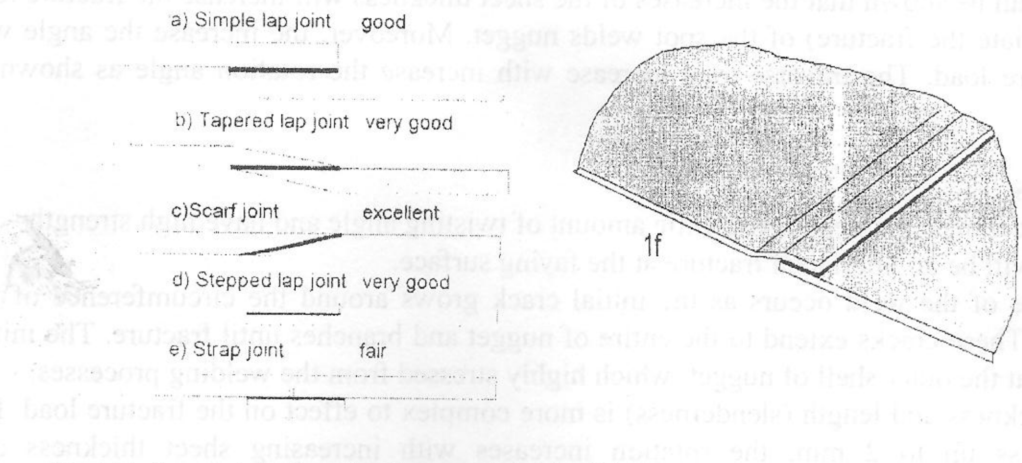

Fig.(1). Lap joints for sheet materials. Ref.2.

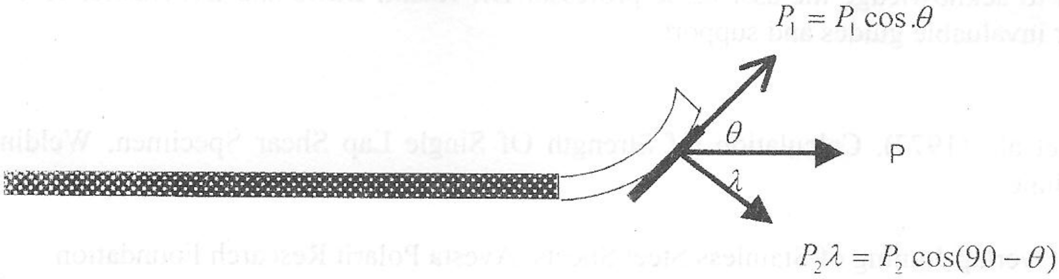

Fig. (2).A.Schematic load distribution in a lap joint.

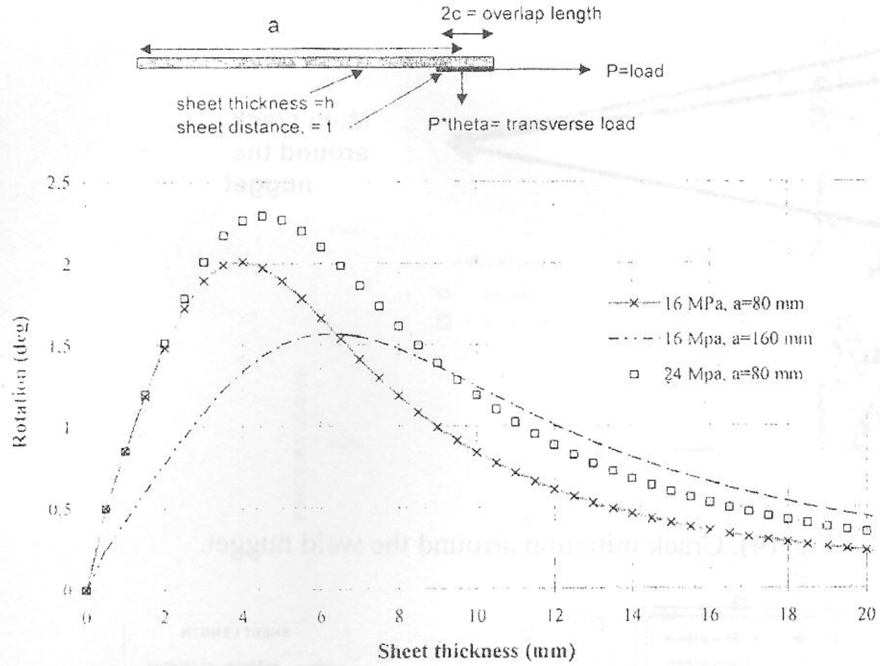

Fig. (2B). Rotation of lap joint with different sheet thickness .

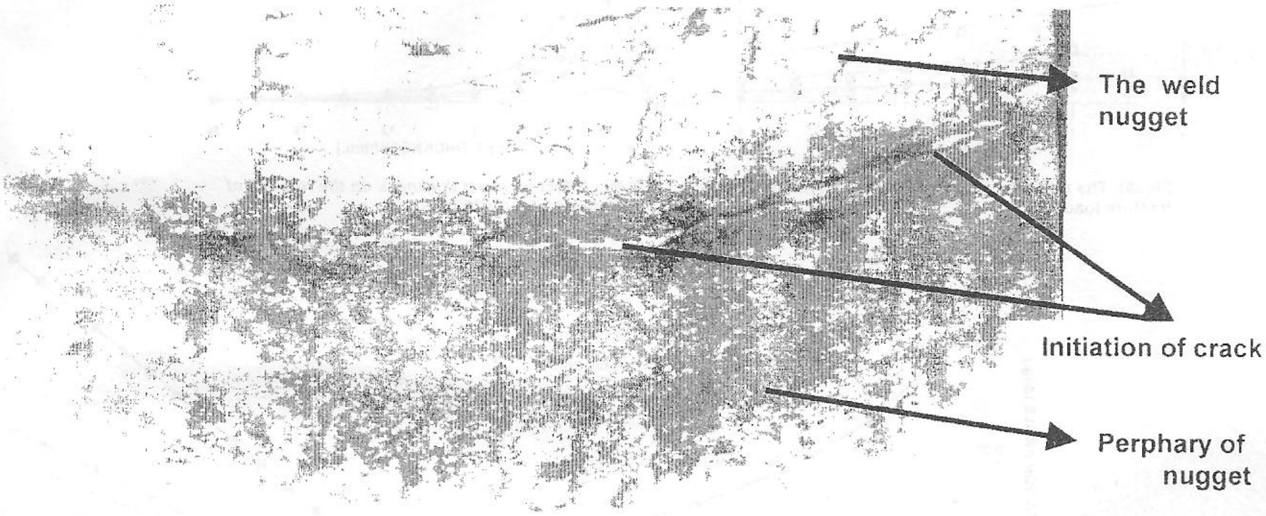

Fig.(3). Fracture initiation site of a lap-shear spot-weld sample.
The hairline at the bottom of the nugget is the crack.

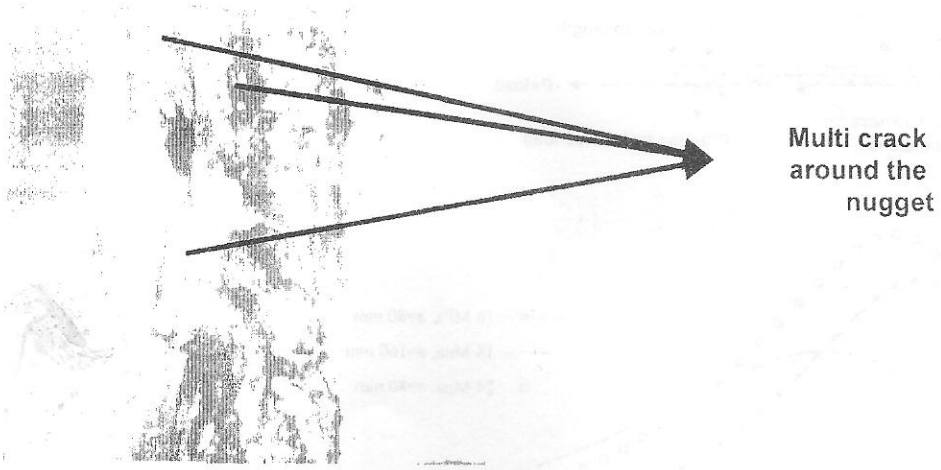

Fig. (4). Crack initiation arround the weld nugget.

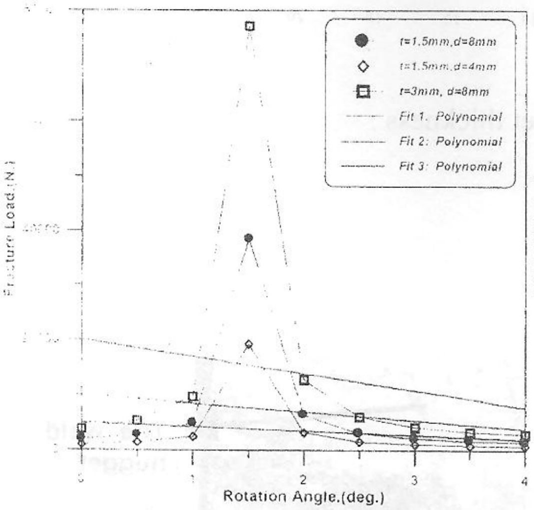

Fig.(6). The relation of the rotation angle and the fracture load.

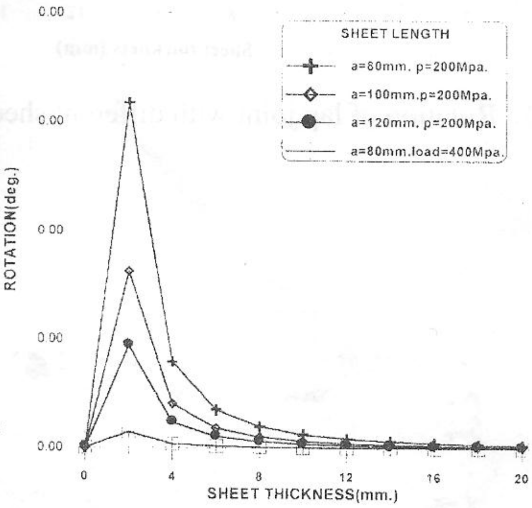

Fig.(5) . Effect of sheet thickness on the rotation of overlapped joint.(b=35mm.)

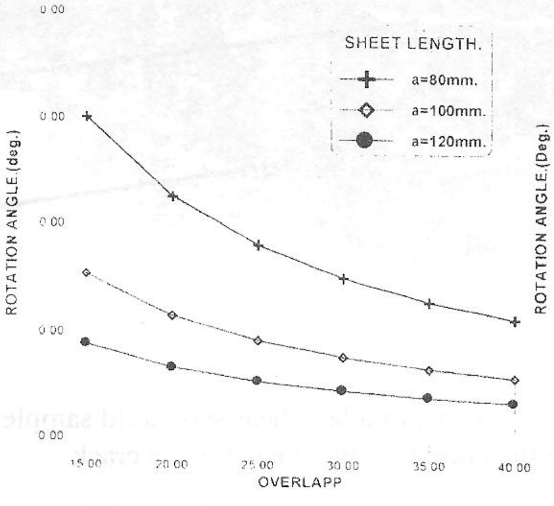

Fig.(7). Effect of overlap distance on the rotation angle of lapped joint.(LOAD=200MPA.THICK.=1.5mm).

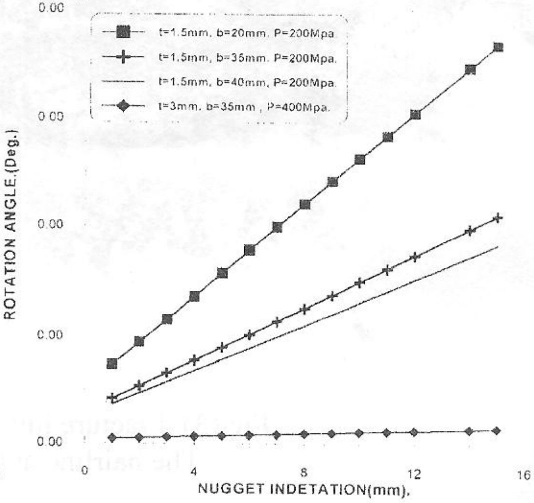

Fig.(8). Relationship of weld nugget indetation and weld joint rotation.

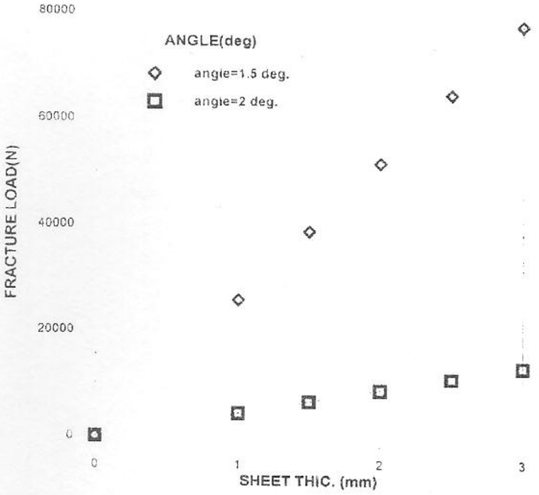

Fig.(9). The relation between the sheet thickness and fracture load