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Numerical Investigation of Intermittent weld Fillet in T – Section Structure – A Comparison with Continuous Weld

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Abstract

In current work, theoretical investigation of two perpendicular plates (joint by a double weld fillets) form a T – section structure made from plain carbon steel was carried out using AUTODESK INVENTOR PACKAGE. The intermittent weld in its two types (stagger and chain) was taken as fastening element in present work. The numerical results (stresses, deformations, and safety factors) were evaluated and compared with continuous weld results. The stagger weld, namely 80(20) arrangement, was being investigated as best arrangement among other arrangements which developed scientific reduction in shear stresses at yz- and xy-plane against chain weld by 15.78 % and 37.86 % respectively. The percentage reduction of safety factors according to Von – Misses stress of 80(20) chain and stagger intermittent welds are 29.78 % and 16.2 % in comparison with continuous weld respectively. The stagger intermittent weld 80(20) is gives lower stresses developed in welded section with higher safety factor.

Key words

Intermittent weld, stress, Autodesc Inventor Package.

Nomenclature

L_w – Effective length of weld in mm.
Q – Shear force in N.
t_w – Effective throat thickness of weld in mm.
T - plate thickness in mm.
σ_w - Design strength of a fillet weld in MPa.
σ_{wn} - Working stress of a fillet weld in MPa.
σ_u - Smaller of the ultimate stress of the weld and the parent metal in MPa.
σ_b - Bending stress in MPa.
σ_n – Normal stress in MPa.
τ – Shear stress in MPa.
γ_{mw} – Partial safety factor.

1. Introduction

Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. It is distinguished from other forms of mechanical connections, such as riveting or bolting, which are formed by friction or mechanical interlocking. It is one of the oldest and reliable methods of joining. The length of intermediate welds should not be less than 4 times the weld size with a minimum of 40 mm. The clear spacing between the effective lengths of the intermittent welds should be less than or equal to 12 times the thickness of the thinner member in compression and 16 times in tension; for each case the length should not exceed 20 cm. The safety factors are **1.25** and **1.5** for shop and field welds respectively [1].

It is sometimes necessary to weld only at regular or irregular intervals along a joint. This is done for several reasons, e.g. to minimize distortion by restricting the heat input or when the load on the welded part is so small that a continuous weld would be uneconomical [2].

Finite element analysis (FEA) has become a practical method of predicting stresses and deflection for loaded structures. FEA accurately identifies the load path, which can be difficult using classical analysis with complex structures. FEA shell element models are effective for predicting loads in weldments fabricated from plate, sheet, structural shapes and tube [3]. The selection criteria for longitudinal versus transverse fillet welds could consider the increased allowable strength associated with the transverse option, reducing the required size. While this option will result in a higher allowable strength, it comes at the cost of reduced ductility in the weld [4].

The air – conditioning equipment and other structure attached to railway rolling stock are plate objects joining by a spot or an intermittent welding. They developed automatic weld modeling technology, with the aim of reducing the procedure for FE modeling with error about 11 % in comparison with experimental data [5]. A measuring of buckling profile of thin – walled steel tube columns due to welding has been developed with zig – zag method using web deflection transducer bar on six thin walled columns [6]

When the stress range is too high for intermittent fillet welds, sometimes the added fatigue capacity associated with continuous fillet is acceptable [7]

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In present work, the numerical investigation of welded perpendicular plates in form of T – section is developed under applying shear force. Two types of weld are taking in T – section continuous and **intermittent** welds with same magnitude of load. The intermittent weld is taken in its two forms **chain** and **staggered** intermittent fillet weld. The finite element analysis was carried out using AUTODESC INVENTOR PACKAGE for continuous and intermittent welds.

Autodesk Inventor is a software package that provides a comprehensive set of design tools for producing, validating and documenting complete digital prototypes—helping manufacturers get to market faster with fewer physical prototypes and more innovative products. Inventor helps designers realize the benefits of digital prototyping by giving them the freedom to reuse their existing drawing designs in a three-dimensional design environment.

2. Theoretical Analysis

The shear stress on fillet weld is [1]:

$$\tau = \frac{Q}{t_w l_w} \qquad \text{.....................(1)}$$

The design strength of a fillet weld shall be based on its throat area :-

$$\sigma_w = \frac{\sigma_{wn}}{\gamma_{mw}} \qquad \text{.....................(2)}$$

$$\sigma_{wn} = \frac{\sigma_u}{\sqrt{3}} \qquad \text{.....................(3)}$$

The total stress magnitude is [3]:

$$\sigma_{weld} = \sqrt{(|\sigma_b| + |\sigma_n|)^2 + \tau^2} \qquad \text{.........(4)}$$

$$\sigma_n = \frac{P}{A_w} \qquad \text{.....................(5)}$$

$$\sigma_b = \frac{M}{S_w} \qquad \text{.....................(6)}$$

Where, $A_w = t_w l_w$

$$S_w = \frac{t_w{}^2 \, l_w}{6}$$

Equations from (1) to (6) are ordinary relations deals with stresses developed in welded fillets which represents the basis of AUTODESK INVENTOR PACKAGE formulation for welding field in addition with finite element formulations for static linear stress simulation in program.

The total stress in continuous weld, as expressed in equation (4), was Von – Misses stress which is determined in present work, while doesn't exist theoretical expressions for intermittent weld. The bending and normal stresses are combined so that their magnitudes are additive; which always be the case on one side of the weld.

For present paper, a method of investigating optimum weld length and spacing for intermittent weld in comparison with continues weld is achieved by evaluation of Von – Misses stresses, shear stresses, deformations and safety factors.

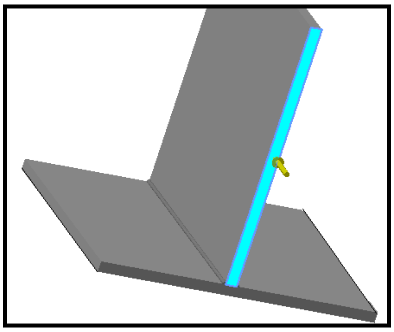
3. Case Study

The problem was taken as case study in current work is a T – section of two equally in dimensions carbon steel plates shown in figure (1-a). The two plates were joined by double continuous carbon steel fillet weld of 10 mm throat size subjected to shear force of ***665 KN*** in middle height of vertical plate [8].

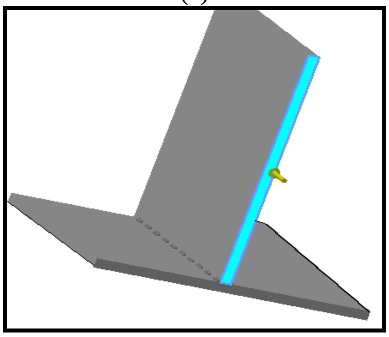
The plate's dimensions are taken 1 x 1 m with thickness ranged between 32 to 50 mm with fillet thickness 10 mm accordance to design of steel structures, i.e. $t_w = 0.25$ T . The plate thickness is taken equal to 40 mm.

The chain intermittent weld of 50(50), i.e. 50 mm weld length and 50 mm spacing between two sequent welds, as shown in figure (1-b) with identical arrangement in two sides. Figure (1-c) is shows the staggered weld of 50(50) with reverse arrangement in other side plate (weld is replaced by space and vice versa). The front view of figure (1) is shown in figure (2) which illustrates details of weld connections.

The mechanical properties of plain carbon steel is listed in Table (1), while mechanical properties for fillet welds made from mild steel is listed in Table (2).



(a)



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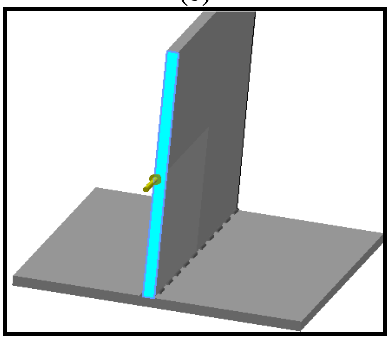


(c)

Figure (1): T – section plates welded by : (a) double continuous weld, (b) chain intermittent weld, and (c) staggered intermittent weld

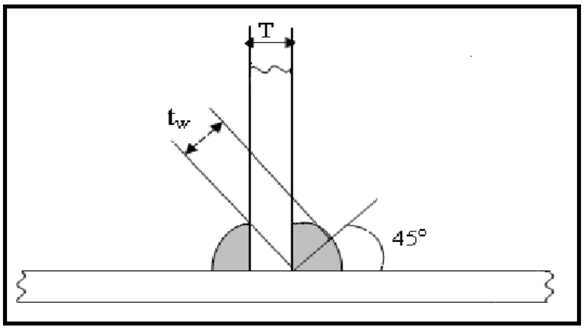


Figure (2): Weld layout.

Table (1): Mechanical properties of plain carbon steel [9].

Modulus of elasticity GPa	Poisson's ratio	Density Kg/m^3	Yield stress N/mm^2
210	0.28	7800	220.6

Table (2): Mechanical properties of mild steel fillet [9].

Modulus of elasticity GPa	Ultimate stress MPa	Density Kg/m^3	Yield stress N/mm^2
200	410	7830	240

4. Results

4.1 Continuous weld

The Von – Misses stress, deformation, shear stress in yz-plane, shear stress in xy-plane, and safety factor developed by applying case study load of ***665 KN*** as given in " Design of steel structures "are shown in figures (3), (4), (5), (6) and (7) respectively at ambient temperature (20° C). The support position of T – section is located in lower surface of lower horizontal plate, which is fixed.

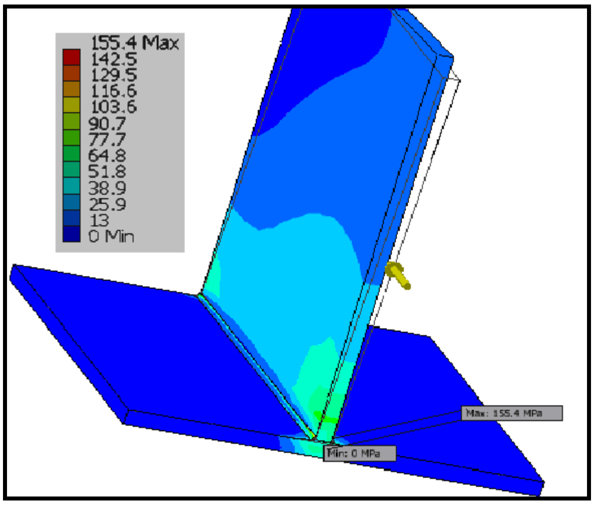


Figure (3): Von – Misses stress of double continuous weld in MPa at 20° C.

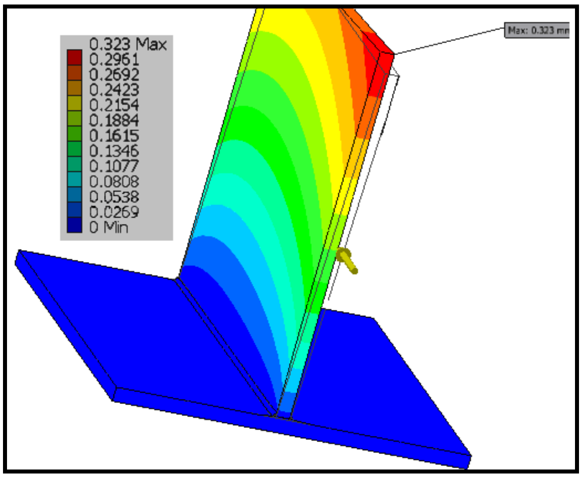


Figure (4): Deformation of double continuous weld in mm at 20° C

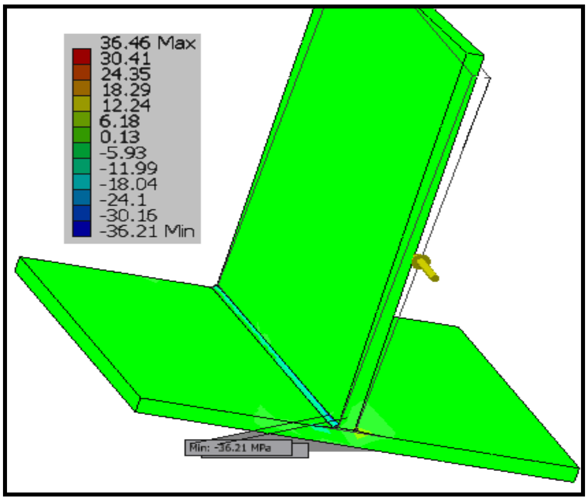


Figure (5): Shear stress in yz-plane of double continuous weld in MPa at 20° C.

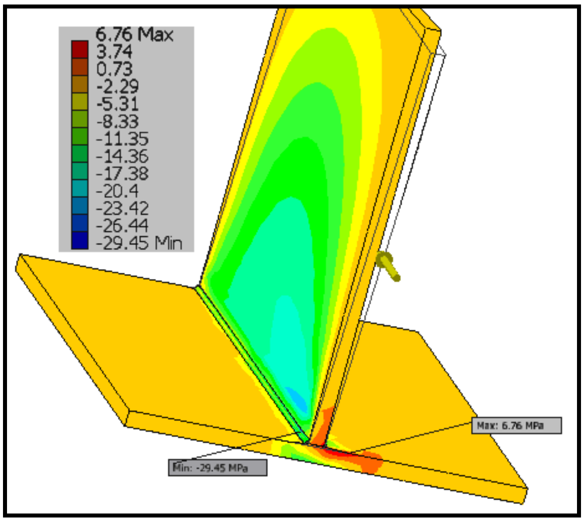


Figure (6): Shear stress in xy-plane of double continuous weld in MPa at 20° C

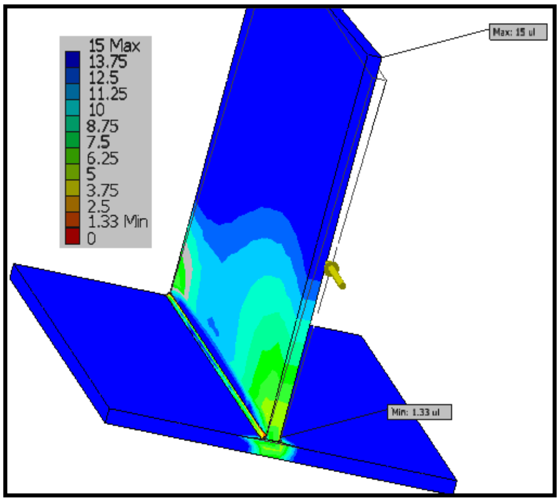


Figure (7): Safety factor of double continuous weld at 20°C.

The negative values of shear stresses shown in figures (5) and (6) were indicated the regions of compression stresses which developed in welded section.

The type of element which used in current work is **SOLID45** shown its layout in figure (8). The SOLID45 is isometric element used for multi – mechanical applications consist of 8 – nodes with three degree of freedom for each node. The number of elements are used in present work about 2564 elements...

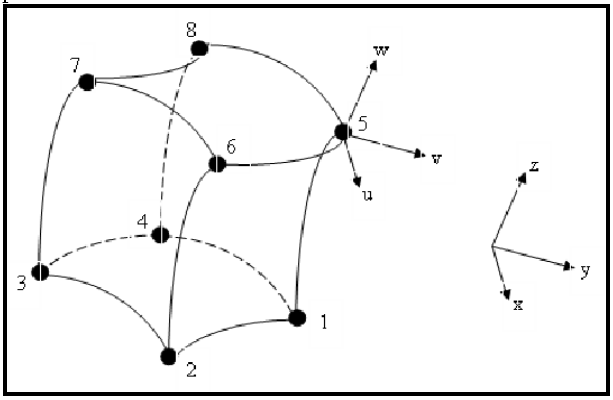
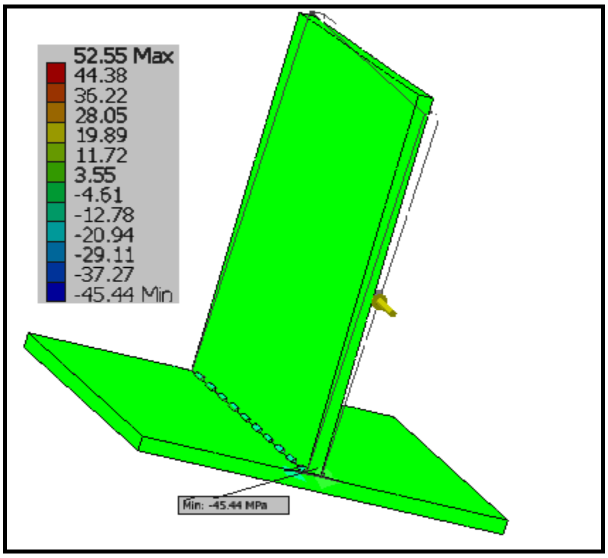


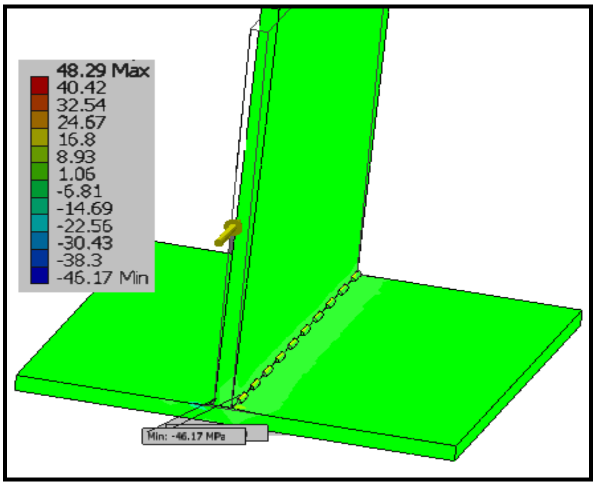
Figure (8): Layout of SOLID45, 8- node element.

4.2 Intermittent weld

The shear stresses for chain and staggered fillet weld arrangement (50(50)) is shown in figures (9) and (10) for yz- and xy- plane respectively. The remaining investigated items for intermittent welds under different combinations of weld length and spacing are shown in Figures (11), (12) and (13) for Von - Misses stress, shear stress at yz-plane, and shear stress at xz-plane respectively. The deformation in all combinations of length and spacing is identical and same as for continuous weld, i.e. **0.323 mm**.

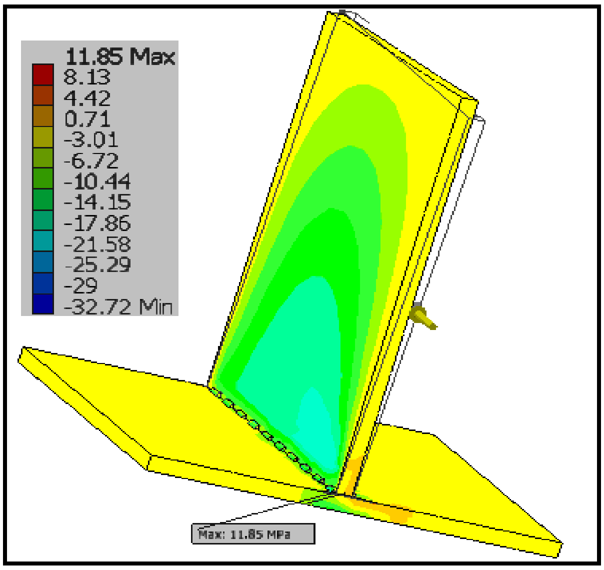


(a)

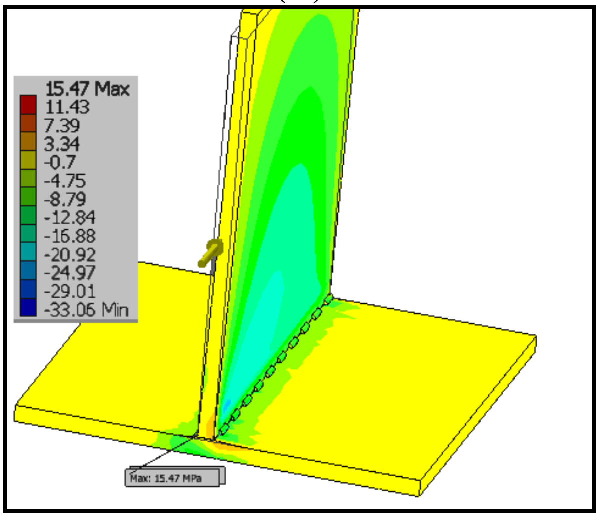


(b)

Figure (9): Shear stress in yz-plane of intermittent weld at 20° C.
(a) chain, (b) stagger



(a)



(b)

Figure (10): Shear stress in xy-plane of intermittent weld at 20° C.
(a) chain, (b) stagger

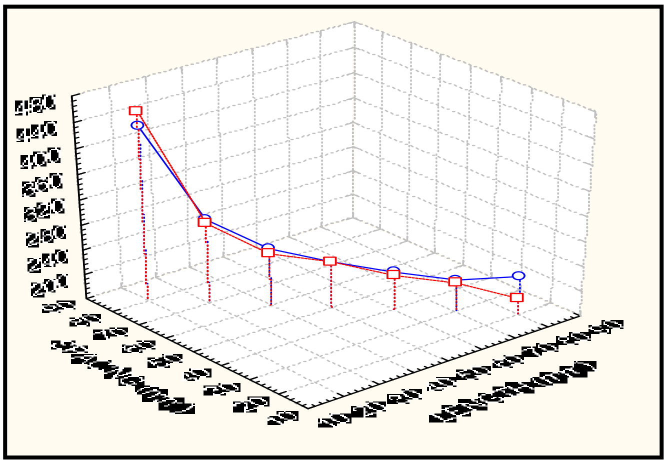


Figure (11): Von - Misses stress in MPa of intermittent weld at 20° C.
○ chain, □ stagger

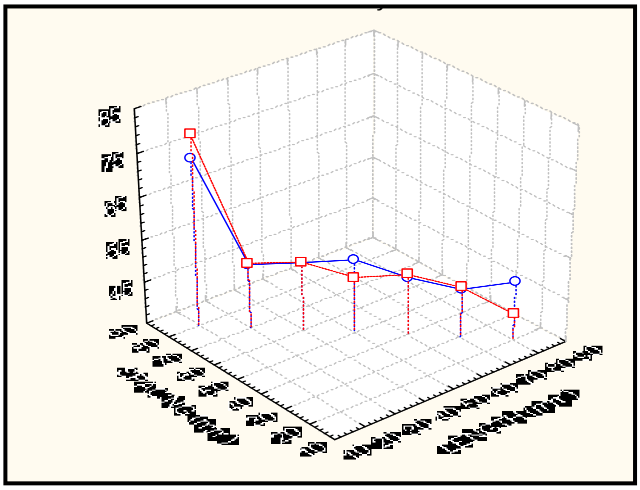


Figure (12): Shear stress in MPa at yz-plane of intermittent weld at 20º C.
○ chain, □ stagger

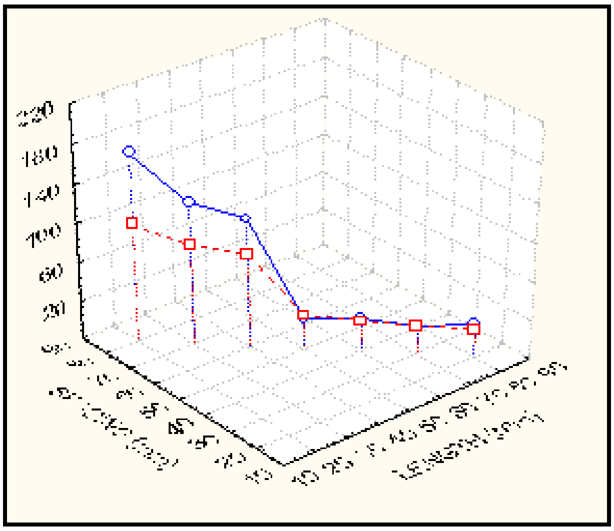


Figure (13): Shear stress in MPa at xz-plane of intermittent weld at 20º C.
○ chain, □ stagger

5. Discussion

In present work; the numerical results are divided in two parts, continuous and intermittent welds. For continuous weld, the maximum Von – Misses stress is **155.4 MPa** at fillet weld (as shown in figure (3)) which represent weaker region and then failure position in overall T – section with minimum safety factor equal to **1.54** according to yield stress of 240 MPa for weld fillet material namely carbon steel which listed in Table (2). The safety factor is calculated according to dividing the yield stress by Von – Misses stress. Figure (4) is shown the distribution of deformation of T - section under study before and after applying the load with maximum value of **0.323 mm** at tip of vertical plate. Maximum deformation on tip of vertical plate is due to fixation of welded structure from lower plate and therefore logically the free end was deformed more than other side.

Maximum shear stresses, as indicated in figure (5) and (6), in fillet weld is **36.46 MPa** and **6.76 MPa** for yz- and xy-plane respectively, because maximum sliding between layers are occur in fillets due to two reasons, first reason existence of different materials (mild and carbon steel) in welded region and then more sliding developed between different molecules with weak bond, while second reason is fillets are lay near fixation of structure. The minimum value located at bottom of vertical plate near weld region for yz-plane.

Factor of safety is ranged between (1.33 **– 15**) with minimum value in weld fillet as shown in figure (7) so its represent weaker region as mention before. The maximum value of safety factor is too high in amount (15); these due two reasons, first one all numerical packages like present program is ranged safety factor for every problem and case study from zero to fifteen, and secondly the blue regions (which has the maximum amount) is free ends with minimum stresses and higher safety factor.

For intermittent weld, shear stresses in yz- and xy- planes are investigated in present work as shown in figures (9) and (10) respectively. The two types of intermittent welds, chain and stagger, for 50 mm length and 50 mm spacing between welds are taken into consideration.

Shear stress in yz-plane is gives higher values against continuous weld by a percentage of **30.6 %** and **24.5 %** for chain and stagger weld respectively, while 43 **%** and **56.3 %** for xy-plane. The change in distribution of shear stress is concentrated at fillets only while constant on one value (green color) for carbon steel plates, due to the stress was estimated on plane yz which located parallel to the plane of fillets and perpendicular to plates.

The effect of additional combinations of lengths and spacing other than 50(50) on Von – Misses stress, shear stress in yz-plane, and shear stress in xy-plane are shown in figures (11), (12), and (13) respectively. Figure (11) is indicate clearly that stagger weld developed lower stresses than chain especially for **80(20)** intermittent weld which gives **185 MPa** against **221.3 MPa** for chain (which more than yield stress of material so not recommended in design), i.e. with reduction of **16.5 %** of Von – Misses stress is gain from using these intermittent weld. Also **80(20)** stagger intermittent weld is developed specific reduction in shear stresses at yz- and xy-plane against chain weld, namely **15.78 %** and **37.86 %** respectively. The safety factors according to Von

– Misses stress are **1.19** and **1.0** for stagger and chain welds respectively; that means chain is make percentage reduction of **29.78 %** while stagger gives only **16.2 %** in comparison to continuous one.

The maximum deformation for all types of intermittent weld (stagger and chain) is same as continuous weld, i.e. **0.323 mm**. The main reason of this phenomena can be explained as for all cases of fillets, maximum deformation is located far away from fillet region (at top and free end of section) and therefore there is no scientific effect of welds on deformation value at this area.

Finally, stagger intermittent weld which different lengths and spacing is gives almost lower stresses than against chain weld with different percentage, therefore can be investigate that staggered weld is better than chain with same lengths and spacing.

In general, intermittent welds were developed higher stresses than continuous weld, but good safety factor is achieved especially for applications not need strong structures. The intermittent weld 50(50) is gain **50%** of weld material against continuous weld, while 60(40) weld is reduced **40%** of weld material, etc. Therefore, cost in material is achieved for other intermittent weld combinations according to its length and spacing.

6. Conclusions

The major points can be concluded from present work are being listed in following two points:

1) Stagger intermittent weld arrangement **80(20)** is best than other combinations of stagger and chain welds due to lower stresses induced in its structure with higher safety factor.
2) The **80(20)** arrangement of stagger intermittent weld is gives percentage reduction **16.5 %**, **15.78 %** and **37.86 %** for Von – Misses stress, shear stress in yz- plane, and shear in xy-plane respectively when it compared to chain weld.

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التحقيق العددي لشريحة اللحام المتقطعة لهيكل على شكل حرفT –دراسة مقارنة مع اللحام المتصل

سمير هاشم امين
معهد اعداد المدربين التقنيين
هيئة التعليم التقني

الخلاصة:

في هذا البحث , تم اجراء التحليل النظري لصفيحتين متعامدتين (موصولة بوصلتي لحام) والتي تشكل هيكل ذات مقطع على شكل حرف T مصنوعة من مادة الصلب الكاربوني باستخدام برنامج AUTODESK INVENTOR. اخذ في هذا البحث اللحام المتقطع بنوعيتية (المتسلسل والمتعاقب) كوسيلة ربط. ان النتائج العددية والمتمثلة بالاجهادات والتشوهات ومعاملات الامان تم حسابها ومقارنتها بتلك المستحصلة من اللحام المتواصل. يمثل اللحام المتعاقب (وبالاخص الترتيب ٨٠(٢٠)) اللحام الانسب ما بين الترتيبات الاخرى والذي يعطي انخفاض ملحوظ في اجهادات القص على المستويات yz و xy بالمقارنة مع اللحام المتواصل وبقدار ١٥,٧٨ % و ٣٧,٨٦ % على التوالي. ان الانخفاظ المئوي لمعامل الامان بالاعتماد على اجهاد فون – مايسز للترتيب ٨٠(٢٠) وللحام المتقطع (المتسلسل والمتعاقب) هو٢٩,٧٨ % و ١٦,٢ % بالمقارنة مع اللحام المتواصل على التوالي. يعطي اللحام المتعاقب ٨٠(٢٠) اقل اجهادات متولدة في مقطع اللحام مع اعلى معامل امان.