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Original Article

Optimization of the Combination of Bolt Position Models and Welding Directions for Tensile Strength

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Abstract - *Research on combination bolted and welded joints by simulating the position of four bolts on combined plate joints with the types of Longitudinal, Transverse, and Combined welding directions (Longitudinal-Transverse) as the development of welded joints of various types of welding directions and bolted joints of various types of several bolts. The connection specimen tensile testing process directly produces the ratio of tensile strength, loading, and elongation at proportional, ultimate, and breaking conditions. This study represents a new approach to the tensile strength of the joint model of the combination of bolt positions to the model of the welding direction. The results of the tensile test show that the bolt position model and the type of welding direction given in the connection affect changes in loading and elongation as well as the ratio of the tensile strength of the plate connection. The position of the four-bolt combination system with a square model with a combination of weld directions (Longitudinal-Transverse) with a constant current strength of 140 Ampere has the highest maximum tensile strength value of 347.222 MPa, compared to the rhombic model with a tensile strength value of 302.593 MPa and the line model parallelogram A of 319.907 MPa and the model of a parallelogram B of 324.815 MPa.*

Keywords - *Optimization, Combination connection, Bolt position model, Welding directions, Tensile strength.*

1. Introduction

The strength of a combination of bolted and welded joints is an integral part of the construction, especially the use of joints in the shipping industry, bridges, building frames, and the automotive industry. The optimal strength of the welded joint is largely determined by the direction of the welding process using the appropriate current strength. [10] The connection must be adapted to the behavior of the plate thickness, the diameter of the bolt with the tightening of the bolt according to the tolerance, and the strength of the connection is also determined by the position of the bolt given to the connection process. [15] The mechanical behavior of the combined bolted and welded joints on the steel plate shows the performance of each. While the ductility of a combination joint increases because it is influenced by bolted and welded joints and the bearing capacity that occurs in the welding process [4]. This shows that the combination of bolted and welded joints produces a greater tensile strength; this also shows the need to modify the standard design of steel structures by combining bolts and welding processes [24]. The combination of both bolts and welds capacity in the finite element simulation directly impacts the correctness of the analysis in theory. That is why it needs universal consideration in selecting every part in setting attributes, dividing the grid, setting boundary conditions, setting the finishing process and obtaining post-treatment results of finite element simulation.

The strength of a welded joint in construction is sometimes unable to accept the load that occurs, for example, a sudden tensile, compressive, or shear load that has never been calculated before. This will damage the welded joint, eventually damaging the construction structural system due to the release of the connection construction elements [21]. As demonstrated, one of the largely used processes in recent industries is gas metal arc welding. Welding current, welding voltage, gas flow rate, wire feed speed, wire size, and welding speed are some of the input factors that play an essential role in recognizing the welding quality. The analysis used is the Taguchi Design to determine the optimal process factor for the tensile strength of various types of welding forms, where a given welding combination has a greater tensile strength value. The combination process of welding joints on commercial steel plates using low carbon steel electrode wire shows that the V shape of the base metal seam has an effect on increasing the tensile strength compared to other types of base metal seams [14]. Stating that the weld joint design method is carried out, either through the longitudinal direction, transverse and the combination of the direction of the weld, it is necessary to use another additional formula for the weld, namely in the corner zones of adjacent structures, the welding process is carried out, this is to produce a good joint construction design based on the load it will receive.

In the automotive industry, using electric current parameters and welding time is the most effective factor in the spot-welding process and determining the effect of the interaction of process parameters on the quality of spot-welding using the Response Surface Method (RSM) [23]. Whereas the process of welding the plate joint experiencing widening of the high-temperature heat-affected zone increases significantly as the applied laser power increases [18]. The tensile strength of the welded joint decreases with increasing laser power, i.e., 1.0 kW, 1.3 kW, and 1.6 kW; their tensile strengths are 723 MPa, 705 MPa, and 695 MPa, respectively, which are 64.55%, 62.95% and 62.05% of the strength base materials. (Y. Chen et al., 2023) Showed that with increasing strain rate, the strength of butt welds (BW), tensile fillet welds (TFW), and shear fillet welds (SFW) increased; butt weld fracture (BW) strain also increased, but the tensile fillet weld (TFW) and shear fillet weld (SFW) decreased. The failure modes of butt welds and tensile fillet welds are significantly affected by matching weld strength, while shear fillet welds are less affected [5].

The connection with the bolted flange plate will change the failure mode of the concrete column, and the reliable welding between the reinforcement and the flange plate plays an important role in the seismic performance of the precast column. When welding damage does not occur, the bearing capacity, ductility, and energy dissipation capacity of the concrete column will not be affected by the column joints [2]. The strength and stiffness of the column increase as the corner thickness increases, and there is a decrease in strength as the deformation occurs; the distance between the heel and the column bolt increases [25]. Building construction to be able to accept and withstand loads from outside the structure requires a combination of bolted and welded connections. This method strengthens bolted and welded connections, where the combined bolted and welded joints each have significantly different deformability. The failure can occur in the shear force of bolts and bolt bearings, so attention must be paid to bolt diameter, plate thickness, and distance between bolts to produce maximum tensile strength [8]. The shear force capacity of the bolt to withstand loading depends on temperature and the axial force relationship [3].

Moreover, changes in the mechanical properties of steel occur due to the gas metal arc welding process. The tensile test results show that in the zone of welding, there is a stress concentration so that the cross-section changes and fails [9]. Increased strength and durability of bolted and welded joints, compared to strength only with bolted or welded joints. Failure of bolted and welded joints occurs due to fatigue withstanding the load, and failure begins in the weld zone, followed by a change in bolt resistance before a fracture occurs [22]. Shows that to determine stress and strain in tensile strength research, it must be adjusted to the plate material and the number of bolts used in the connection. In the bolt connection process, it is necessary to pay attention to the plate's resistance in the bolt tightening system because the friction force occurs due to the connection's pre-tightening force and influences the plate's behavior, which can experience static deformation.

The problem often occurs in bolted connections is the large shear force when subjected to a tensile or compressive force in the connection construction. Moreover, the connection is through welding in construction, where problems occur in the weld zone, which often cracks or breaks when subjected to heavy loads. Therefore, this bolt & weld combination joint can reduce cracking in the joint zone, model the weld and bolt combination joint, and also produce the tensile strength of various types of joints, and also produce a combined model of bolted position joints of various welding directions, both longitudinal type, transverse and a combination of directions, namely longitudinal and transverse.

To know the effective combination of joints in steel construction, simulation of welding on combined joints is necessary for several different reasons. One of them is the use of variations in the direction of the welding process and the model of the bolt connection position. Increasing the strength of combined bolted and welded joints can be obtained through the use of a longitudinal, transverse, and combined (Longitudinal-Transverse) welding direction connection system and by providing variations in the position of the four rectangular, diamond, and parallelogram bolts. This study represents the novelty of the tensile strength of the joint model of the combination of bolt positions to the model of the welding direction.

2. Methods

The method used in this research is experimental research and literature review on the effect of various bolt position models with variations in the direction of the welding system in strengthening the tensile strength of the combination of bolted and welded joints. The stages of the research were carried out by making test specimens for the model of the position of the bolt joints in the shape of a square, diamond, or parallel program. The direction of the type of welding that was carried out was the longitudinal, transverse and combined direction of the connection (longitudinal-transverse), and then tensile testing was carried out. The design of the tensile strength test specimen uses steel plate material; the bolts used are M13 bolts with tensile strength; 932,398 MPa is manually tied with a torque of 25 Nm. The dimensions of each connection specimen are; 90 x 150 mm and 60 x 150 mm; the thickness of each connection specimen plate is 6 mm each, manual welding process with SMAW using ESAB 601 electrodes. Each specimen is then welded and bolted following the research preparation settings, and the connection model combination of the direction of the weld to position 4 bolts are:

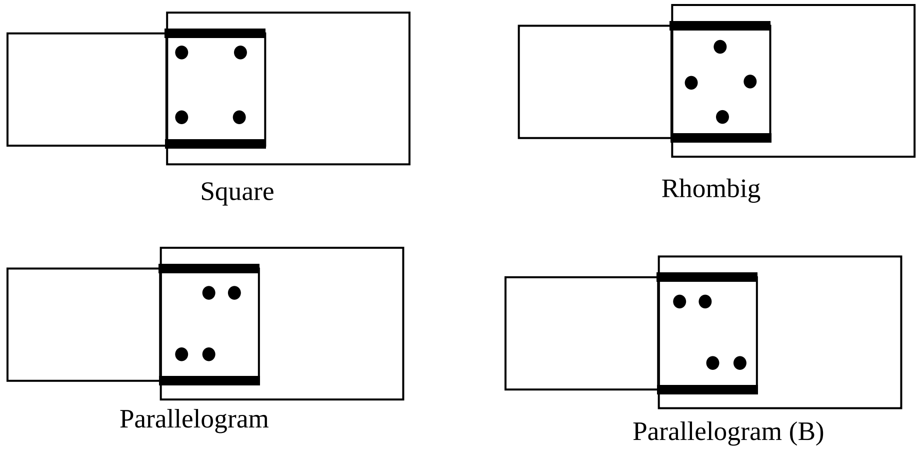


Fig. 1 Longitudinal models

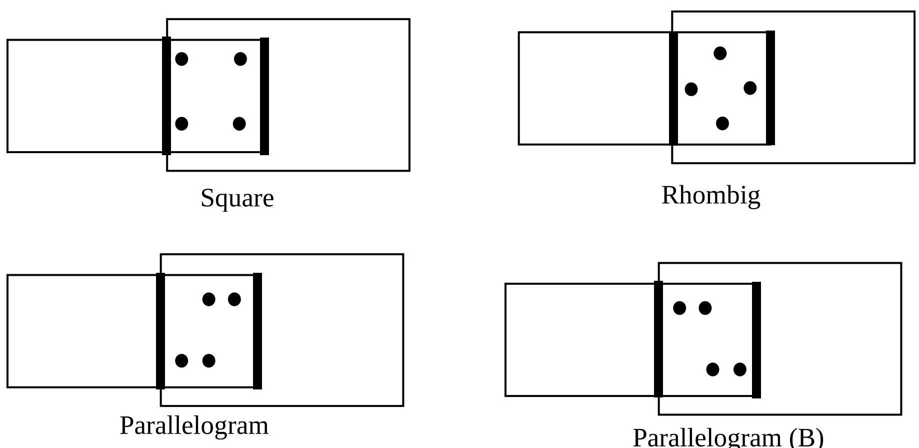


Fig. 2 Transverse models

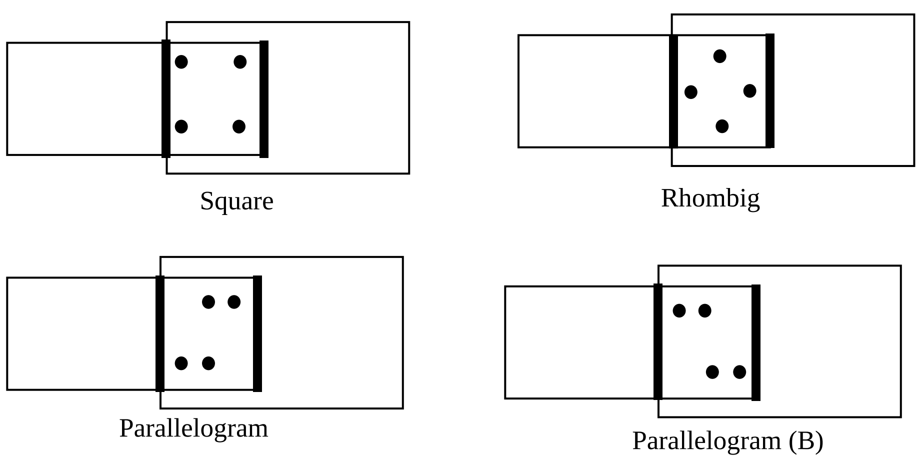


Fig. 3 Combination models

The strength of a combination of bolts and welds is an integral part of the construction, and the need for the use of this connection is widely used in the shipping industry, bridges, building frames, and the automotive industry. The optimal strength of the welded joint is determined by the direction of the welding process and the use of the appropriate current strength, as well as the strength of the bolted connection, which is determined by the shape and model of the bolt position given in the connection process.

To determine the tensile strength of each, the process of making connection specimens for longitudinal, transverse, and combined directions (longitudinal-transversal) welding is carried out, and the welding process is carried out with a constant current strength of 140 Amperes. Bolts are subjected to a nut-tightening process to produce a constant torque before carrying out the tensile strength test.

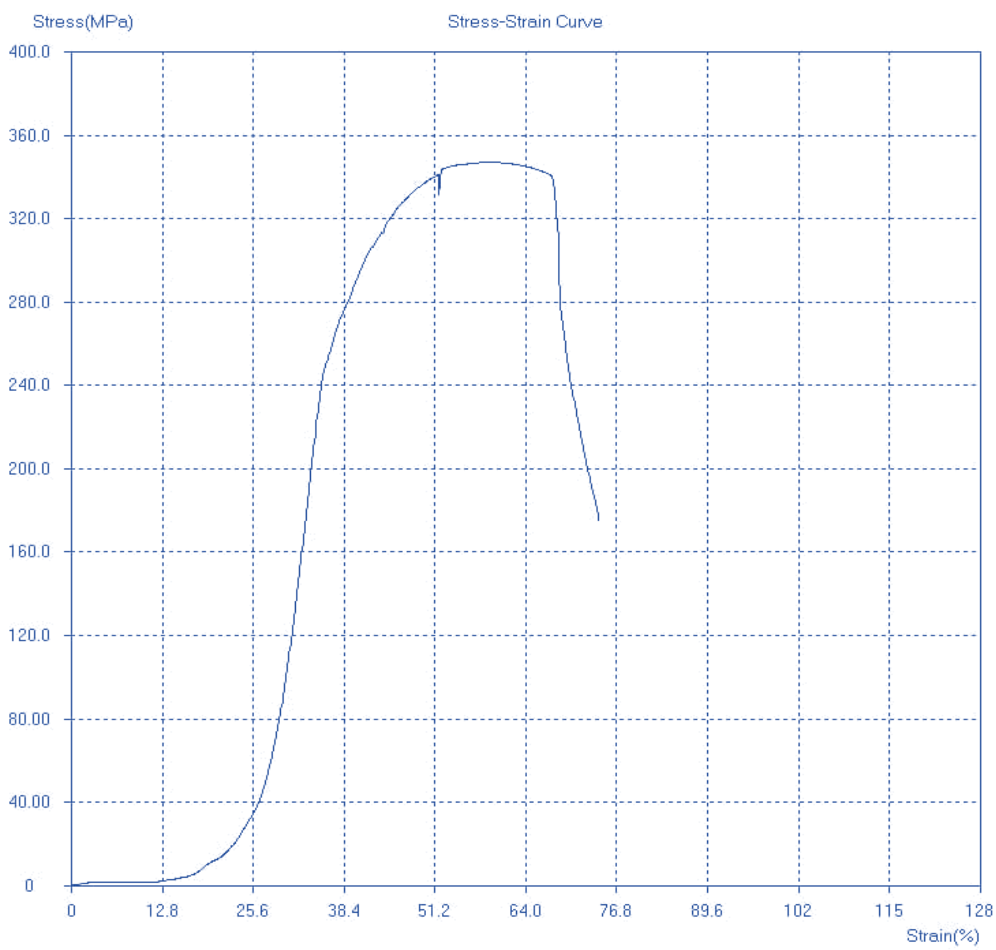
The process of testing the tensile strength of the joints shows several conditions for each test specimen, starting from proportional conditions, yielding, ultimate and breaking conditions (break). The tensile strength of the 4-bolt position model against the strength of the welding direction current in the tensile strength test each produces a value of tensile strength, strain, elongation, time, and load from the tests carried out. From the results of this test, the influence of the relationship between the bolt connection position model and the welding process direction model was analyzed to produce the best combination joint position model and, as a reference, a reference for industries engaged in construction using plate metal connection models.

3. Results and Discussion

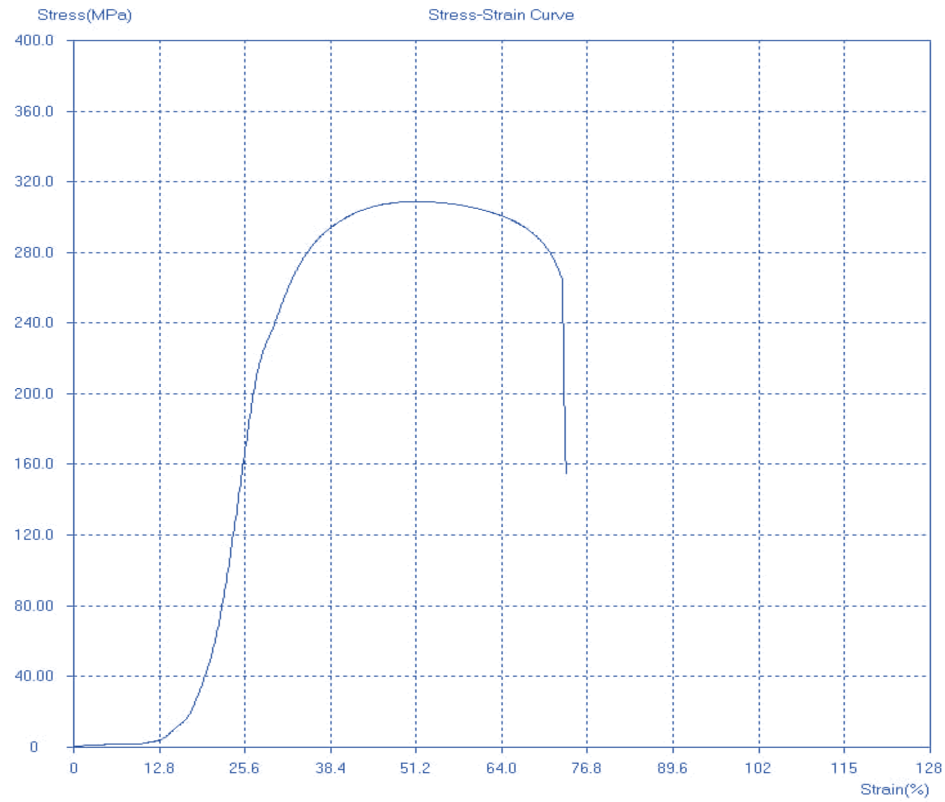
The results of the tensile testing of 4 bolt-welded combination joints from various position models show strength variations from the following graphic images; Testing of tensile test specimens from various three models of connection positions experienced proportional, yielding, maximum, and fracture conditions, but the maximum tensile strength values varied. The 4-bolt square position model for the combination of longitudinal-transverse welds is the best position model for the tensile strength test results compared to the longitudinal and transverse welding treatments (Fig 4).

Likewise, for testing tensile test specimens for the diamond position model shown in Fig 5.

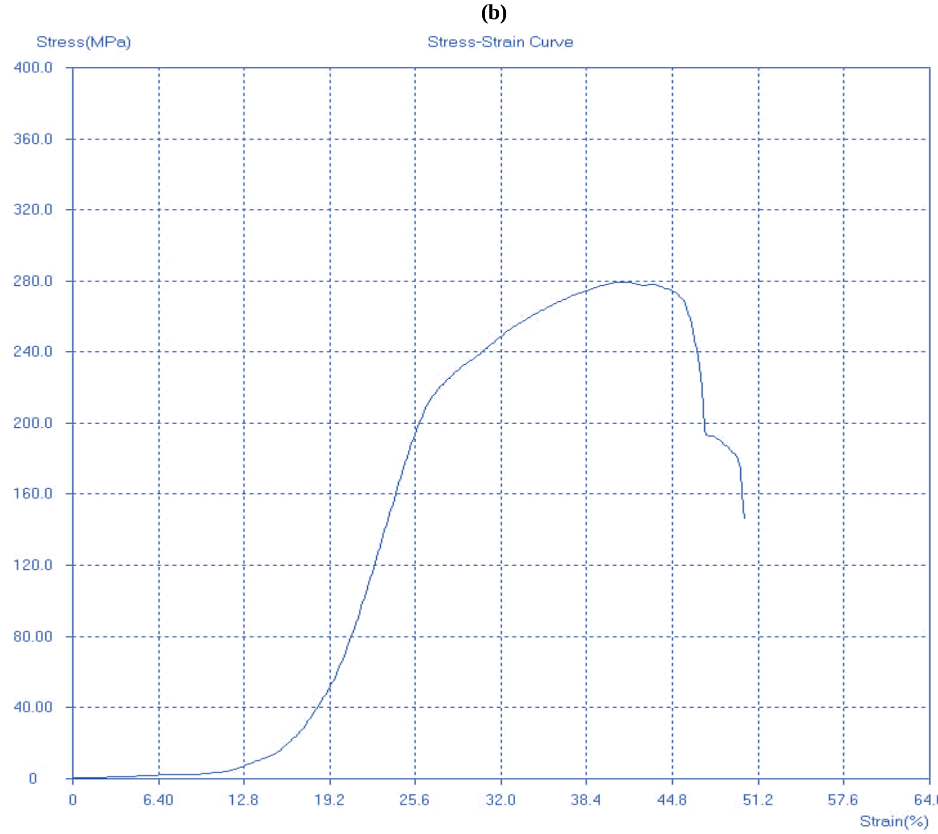
Further testing of the tensile test specimen with the parallelogram position model A shows that the combined (longitudinal-transverse) weld has the greatest tensile strength compared to the longitudinal and transverse directions (Fig 6).



(a)

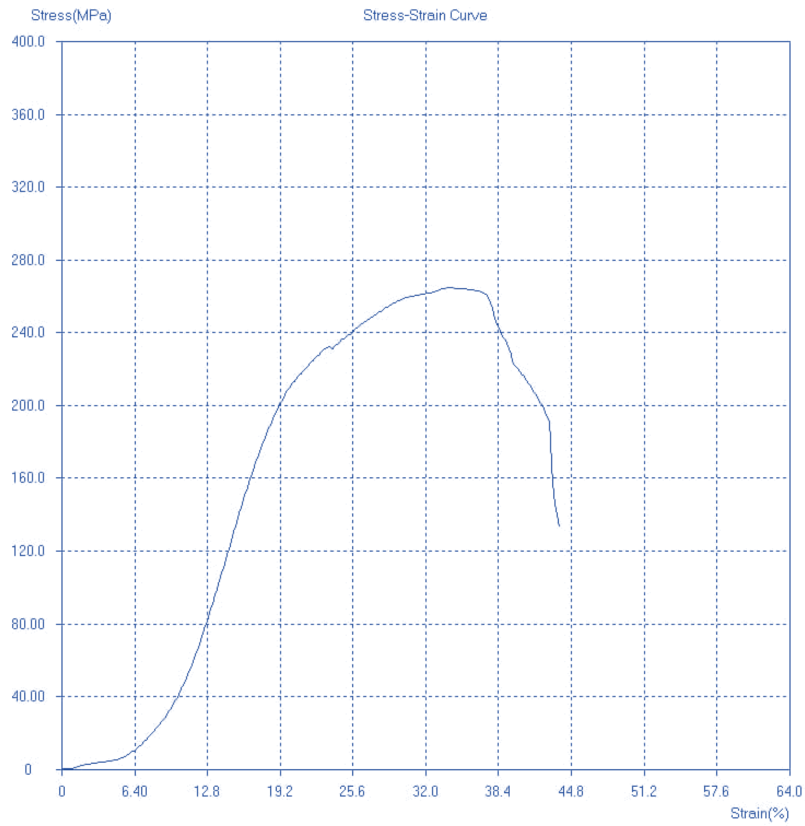


(b)

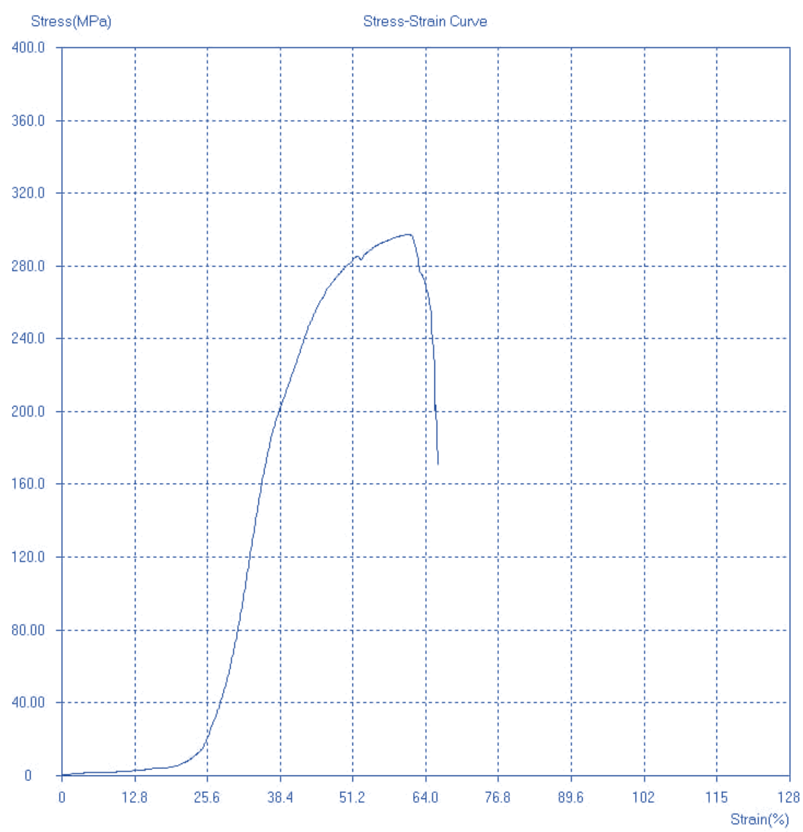


(c)

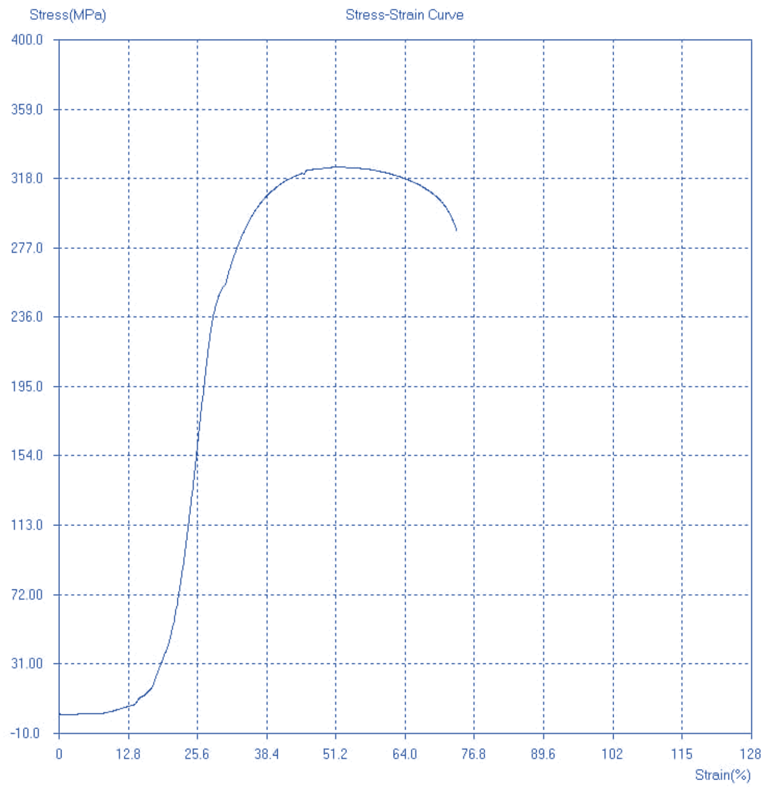
Fig. 4 Graph of the relationship of tensile strength to the strain of the Las-Bolt combination of the square with the type of welding direction; (a). Longitudinal, (b). Transverse, and (c). Combination (Longitudinal-Transverse)


Stress(MPa)
Stress-Strain Curve
400.0
360.0
320.0
280.0
240.0
200.0
160.0
120.0
80.00
40.00
0
0
6.40
12.8
19.2
25.6
32.0
38.4
44.8
51.2
57.6
64.0
Strain(%)

(a)

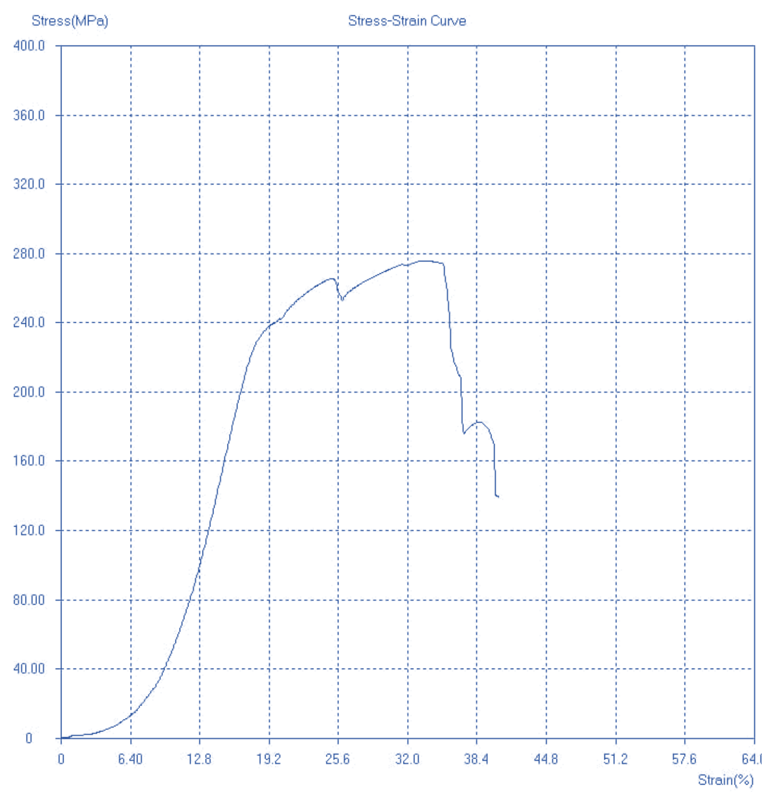

Stress(MPa)
Stress-Strain Curve
400.0
360.0
320.0
280.0
240.0
200.0
160.0
120.0
80.00
40.00
0
0
12.8
25.6
38.4
51.2
64.0
76.8
89.6
102
115
128
Strain(%)

(b)

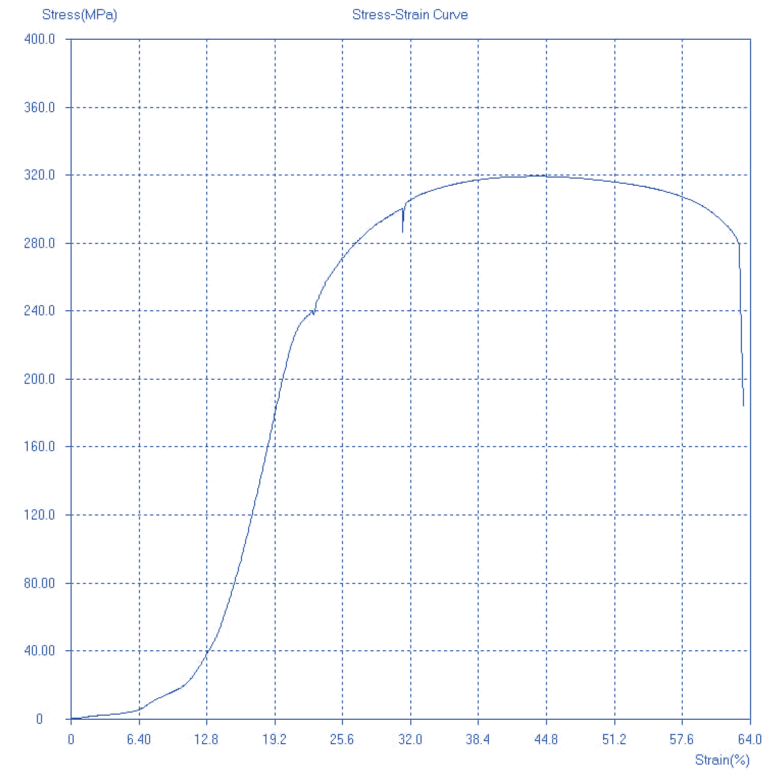


(c)

Fig. 5 Graph of the relationship of tensile strength to the strain of the Las-Bolt combination of the Rhombic with the type of welding direction; (a). Longitudinal, (b). Transverse, and (c). Combination (Longitudinal-Transverse)



(a)



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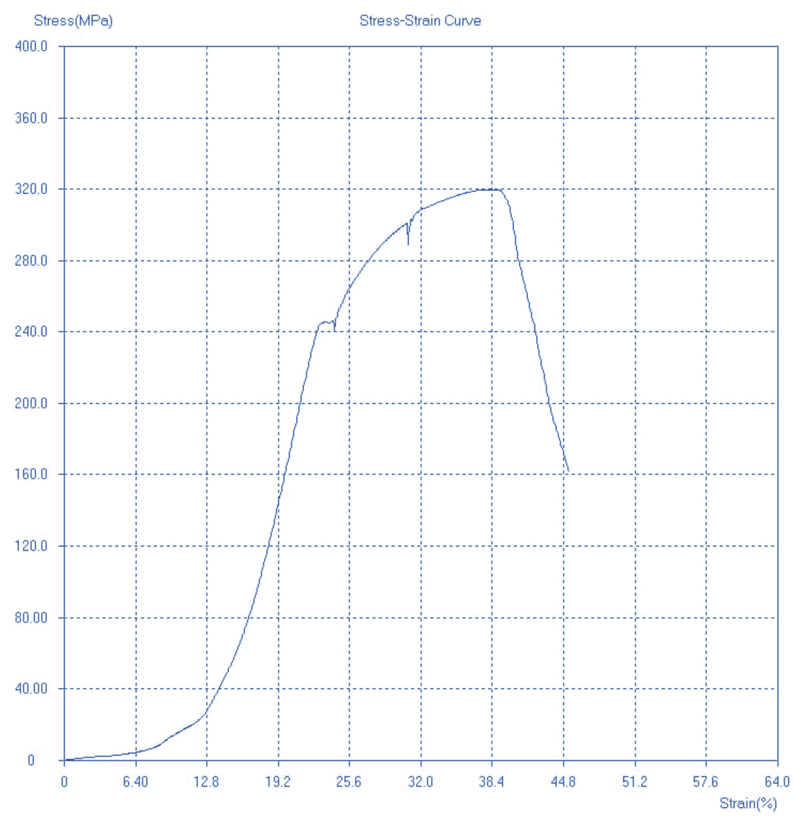
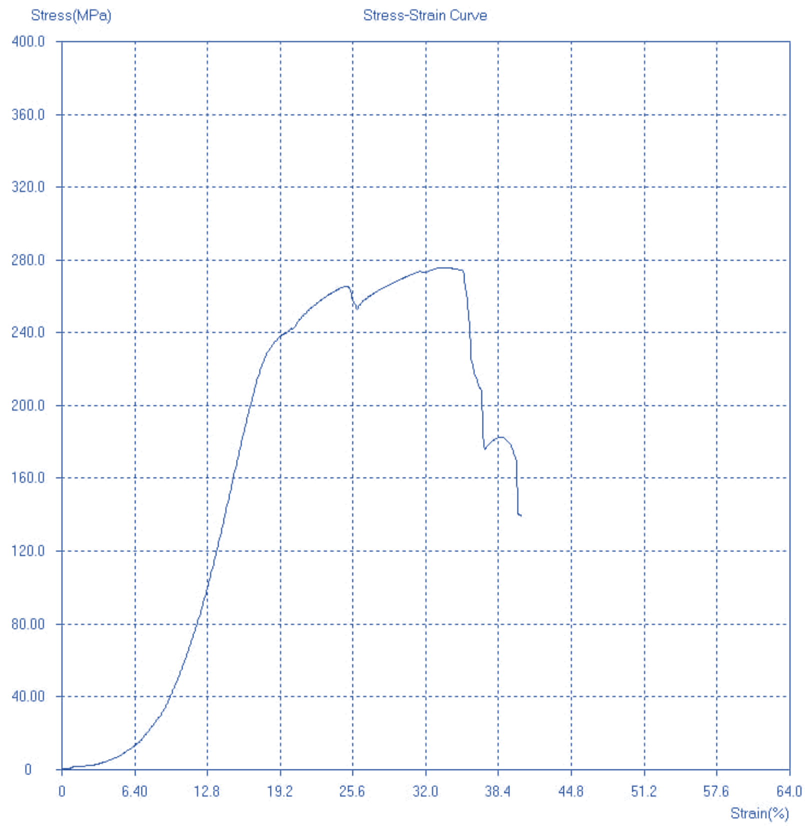
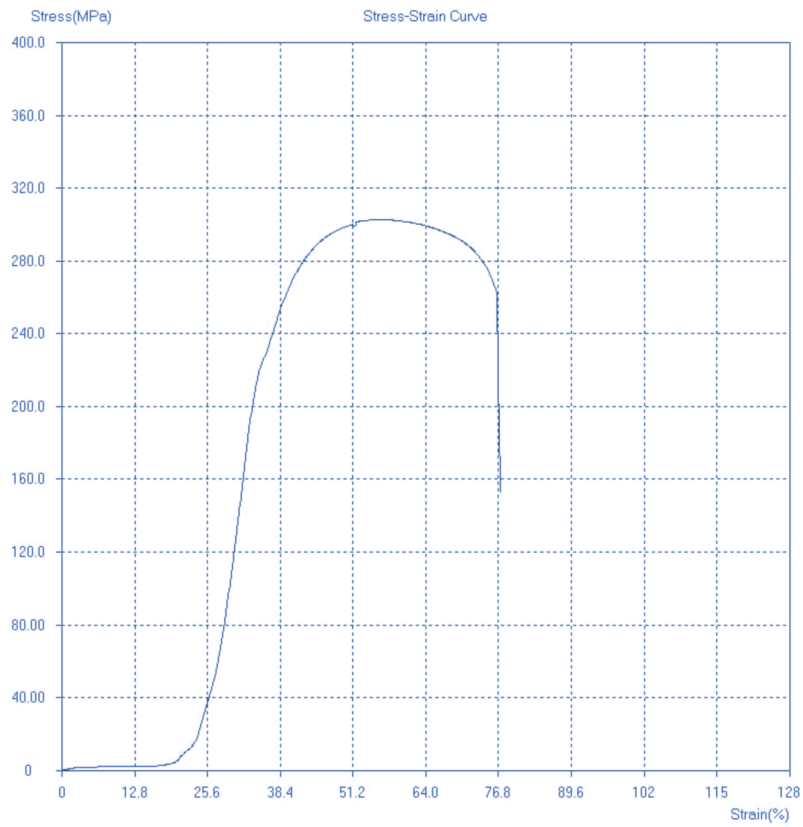


(c)

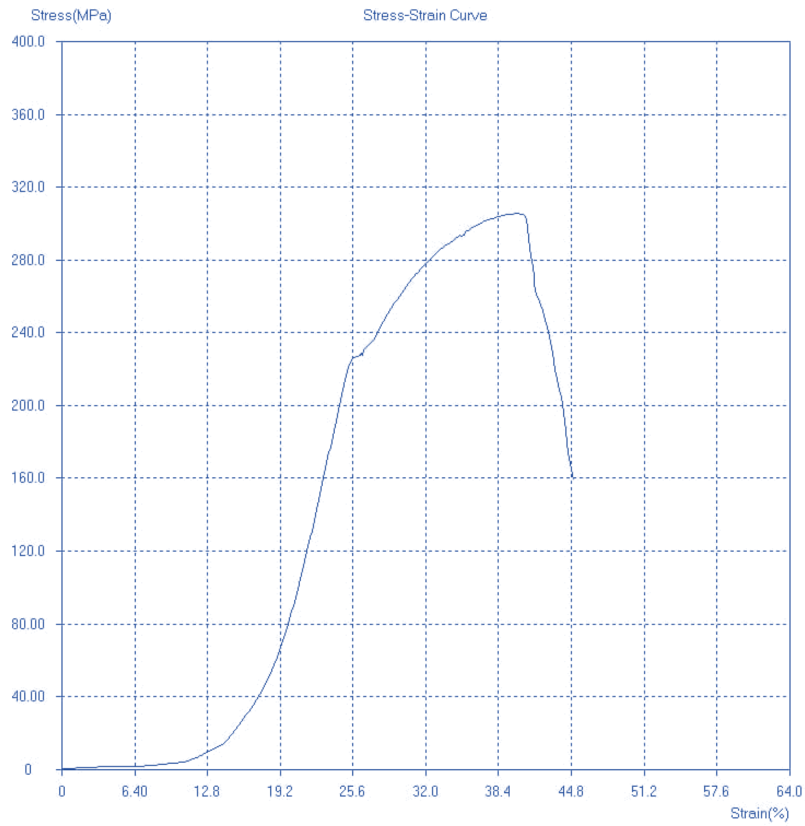
Fig. 6 Graph of the relationship of tensile strength to the strain of the Las-Bolt combination joint, Parallelogram Model A, welding direction; (a). Longitudinal, (b). Transverse, and (c). Combination


Stress(MPa)
Stress-Strain Curve
400.0
360.0
320.0
280.0
240.0
200.0
160.0
120.0
80.00
40.00
0
0
6.40
12.8
19.2
25.6
32.0
38.4
44.8
51.2
57.6
64.0
Strain(%)

(a)


Stress(MPa)
Stress-Strain Curve
400.0
360.0
320.0
280.0
240.0
200.0
160.0
120.0
80.00
40.00
0
0
12.8
25.6
38.4
51.2
64.0
76.8
89.6
102
115
128
Strain(%)

(b)



(c)

Fig. 7 Graph of the relationship of tensile strength with the joint strain of the Las-Bolt combination, parallelogram B, Model of welding direction; (a). Longitudinal, (b). Transverse, and (c). Combination (Longitudinal-Transverse)

Testing of the tensile test specimens for the parallelogram position model B shows that the transverse direction weld has the greatest tensile strength compared to the longitudinal direction and combination (longitudinal-transverse) welding processes, as shown in Fig 7. Graph of the relationship between stress-strain. The process of testing the tensile strength of various models of bolt connection positions experiences proportional, yielding, maximum, and breaking conditions, but the maximum tensile strength values vary.

The results of testing the bolt connection with the longitudinal weld direction from various bolt position models (square, rhombic, parallelogram A and B) show a decrease in tensile strength due to the influence of fast deformation in the weld zone, affecting the tensile strength ratio. Subsequent tests were carried out in the transverse welding direction, which deformed slightly slowly in the weld zone and affected the increase in the tensile strength ratio. Tensile testing of bolted connections with the combined (longitudinal-transverse) welding direction shows a significant slowdown in the ultimate condition towards the break. This indicates that almost simultaneous deformation occurs in the weld zone and bolted joints with greater tensile strength. The test results for bolt-welded combinations are shown in Table 1.

Table 1. Tensile strength values for welded bolted joints

Bolts Position Model	**Tensile Stress (MPa)**		
	Longitudinal	Transverse	Combination
Square	279.444	308.889	347.222
Rhombic	264.815	297.222	302.593
Parallelogram (a)	275.741	319.259	319.907
Parallelogram (b)	270.185	324.815	305.556

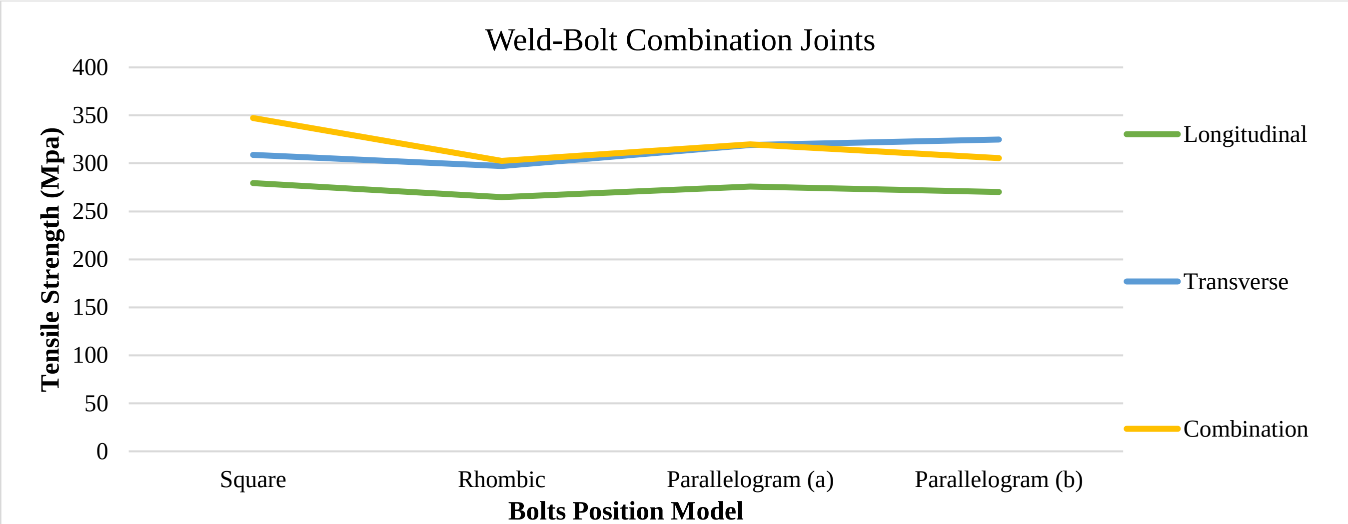


Fig. 8 Graph of the relationship between tensile strength and connection model combination of joint bolt position types of welding directions

Based on the results of testing the tensile strength of the welded combination connection to the 4-bolt position at a current strength of 140 Amperes, the square model shows the value of the ultimate tensile strength of each connection model. The test results show that a rectangular model position in the longitudinal direction has a maximum tensile strength of 279,000 MPa, for the transverse direction, 308,889 MP, and for the combined (longitudinal-transverse) direction, 347,222 MPa.

Furthermore, for the position of the diamond model, it shows that the maximum tensile strength in the longitudinal direction is 264.815 MPa, for the transverse direction 297.222 MPa, and in the combined (longitudinal-transverse) direction, 302.593 MPa. Then proceed again for the position of the parallelogram model A, which shows the maximum tensile strength of the longitudinal direction type of 275.741 MPa, the transverse direction type as 319.259 MPa, and the combined direction (longitudinal-transverse) as 319.907 MPa.

While the position of the B-type parallelogram model shows the maximum tensile strength in the longitudinal direction of 270.185 MPa, in the transverse direction of 324.815 MPa, and in the combined direction (longitudinal-transverse) of 305.556 MPa. the position model of the number of bolts is shown in the following graph.

The graph of the bolt-welded combination shows the effect of variations in the model of the bolt position and the type of welding direction on the tensile strength of the joint. Meanwhile, the design of a bolt-welded combination connection only uses longitudinal welding with two bolts in the same direction as the tensile force shows that the mechanical behavior in the joint combination is the same, the bearing capacity of the bolts does not affect the bearing capacity of the weld, but in the acceptance of the load in the combined joint, it shares the strength ratio—weld – bolt [16].

In addition, the structural behavior and resistance of S700 high-strength steel double shear bolt connection with 1-bolt, 2-bolt, and 4-bolt connections. Two kinds of failure modes, i.e. net section fracture and bearing failure, the effect of various geometric parameters on failure loads and modes of double shear bolt connection specimens, it was found that the fracture behavior and resistance of the mesh section are sensitive distancing and cross distancing of edge, whereas the resistance and behavioral bear more depending on the longitudinal and tip distance [12].

The ultimate tensile strength value for the combination system in the direction of welding to the position of 4 bolts from various types of models that occurs is also followed by changes in the conditions of stretching, loading, elongation, and time used to reach their respective ultimate points.

In detail, the value of the ultimate tensile strength at ultimate each in the combined welded connection system for the 4 bolt positions of various types of models is shown in Table 2.

The results of the ultimate tensile strength test show that the joint system combined in the direction of the weld (longitudinal-transverse) to the position of the 4 bolts in the square model has the highest maximum tensile strength value, 347.222 MPa, and the system in the longitudinal direction of the welded joint with the rhombus model shows the value of the tensile strength the lowest maximum is, 264.815 MPa as shown in table 1 the results of the tensile test [19].

Stating that the combination joint in the longitudinal direction of welding with 2 bolts to the joint plate produces a tensile strength of 290 MPa with a coefficient of friction of 5.0 and the strength between the bolt and the weld is 1:0.30, indicating that the combined bolt and weld connection has an advantage in the design of steel structures.

Table 2. Tensile strength values for bolted and welded joint systems

Number of Bolts	Type	Condition	Time (S)	Loads (KN)	Extension (mm)	Tensile Stress (MPa)	Strain (%)
4 BOLTS	Square	LONG	35.345	150.9	20.42	279.444	40.84
		TRANSV	43.536	166.8	25.176	308.889	50.352
		COMBINATION	58.623	187.5	29.379	347.222	58.758
	Rhombic	LONG	29.351	143	16.987	264.815	33.974
		TRANSV	52.429	160.5	30.35	297.222	60.7
		COMBINATION	55.026	163.4	27.551	302.593	55.102
	Parallelogram (a)	LONG	50.231	148.9	16.57	275.741	33.14
		TRANSV	63.918	172.4	21.15	319.259	42.3
		KOMB	58.624	172.75	19.378	319.907	38.756
	Parallelogram (b)	LONG	27.453	145.9	15.889	270.185	31.778
		TRANSV	104.478	175.4	25.441	324.815	50.882
		COMBINATION	39.942	165	19.915	305.556	39.83

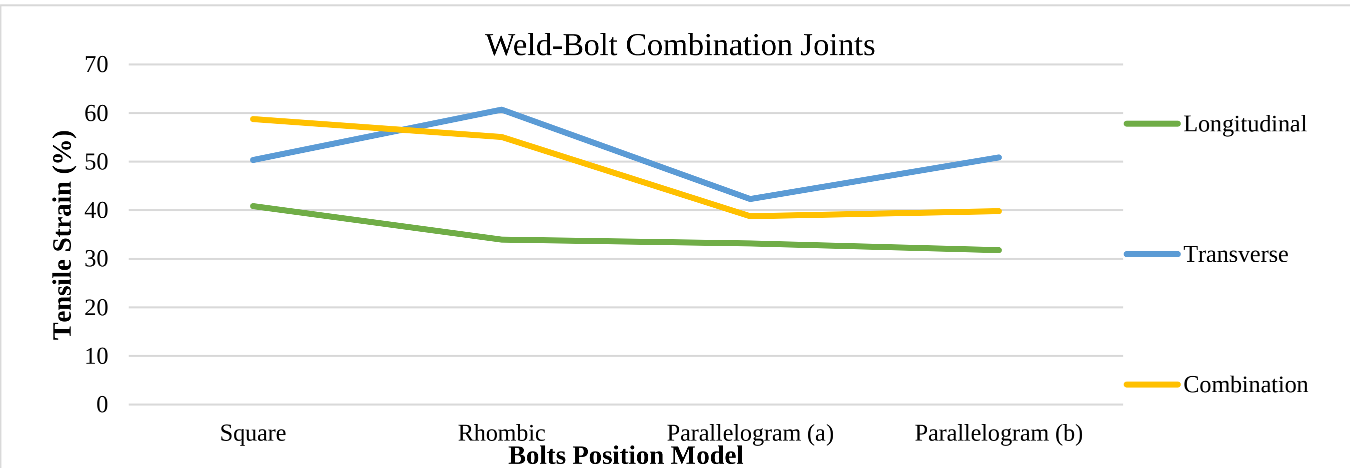


Fig. 9 Graph of the relationship between tensile strain and Bolt-Weld position combination joints

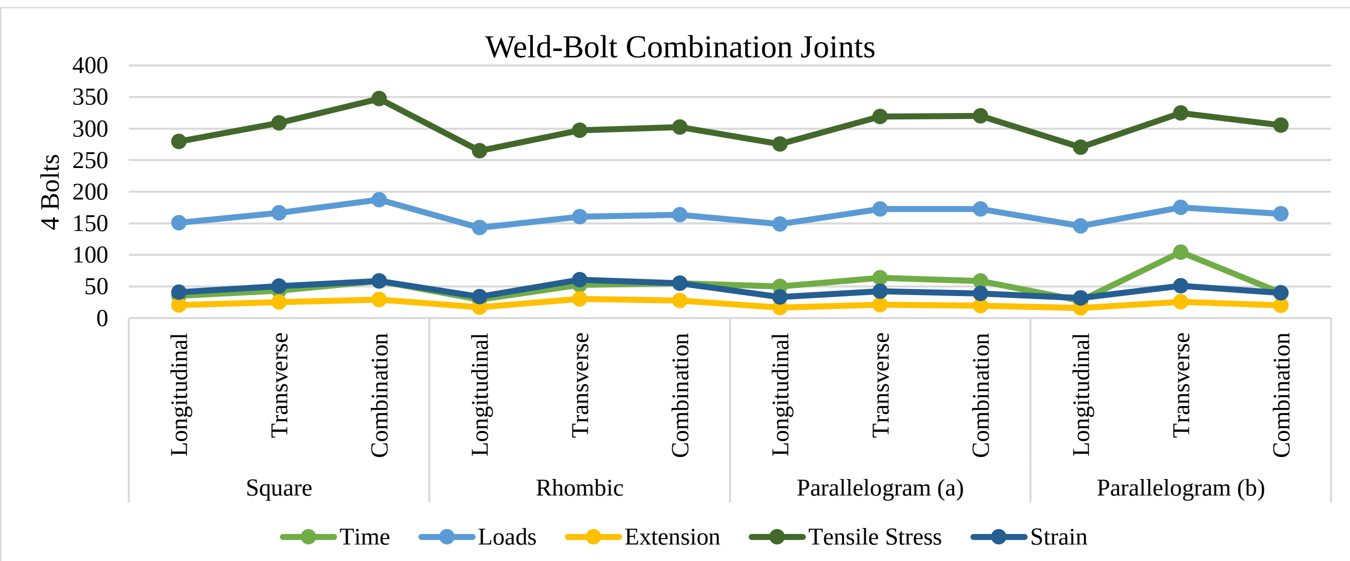


Fig. 10 Welding combination connection to the 4-Bolt position model with a current strength of 140 ampere ST Plate. 42.

Based on the results of the tensile test of the combination of bolts and welds at a current strength of 140 amperes, it also shows the variation of time required to reach the maximum tensile strength at the ultimate of various types of bolt position models, namely for a rectangular model in the longitudinal direction of 35.345 seconds, type of direction transversal of 43.536 seconds and the combined direction of 58.623 seconds. In the rhombus model, the longitudinal direction is 29.351 seconds, the transverse direction is 52.429 seconds, and the combined direction is 55.026 seconds.

While the parallelogram model A with the type of longitudinal direction is 50.231 seconds, the type of transverse direction is 63.918 seconds, and the type of combination direction is 58.624 seconds. In the position of the parallelogram model B with the type of longitudinal direction of 27.453 seconds, the type of transverse direction of 104.478 seconds, and the type of combination direction of 39.942 seconds. The condition of the relationship between the stretching system and the time used in the tensile test is shown in the following graph.

The increase in the value of the load that occurs in the maximum tensile strength test results for the combination of the 4 bolt position combination models of square, rhombus, parallelogram A, and parallelogram B models of the transverse, longitudinal, and combined welding joints at a current strength of 140 Amperes also affects the increase in the strain value (%) and the time used when the load is ultimate until it reaches the break connection condition. In the position of the diamond model, the type of longitudinal direction of 33.974 %, the type of transverse direction of 60.700 %, and the type of combination direction of 55.102 %. Whereas in the position of the parallelogram B model with the type of longitudinal direction of 31.778 %, the type of transverse direction of 50.882%, and the type of combination direction of 39.830 %. Specifically, the phenomena that occur from the results of testing the strength of the combined welded joint system on the 4-bolt position model show the tensile strength, stretching, loading, elongation, and maximum time values in Fig 9 of the graph.

Based on the results of the tensile strength test of the combination of 4-bolt position combinations of a square, rhombus, parallelogram A, and parallelogram B models for the transverse, longitudinal, and combined (longitudinal-transversal) welding joints at a current strength of 140 Amperes shows that the welded joints in the transverse direction for the 4 bolt position the diamond model has the highest tensile strain value of, 60.700 % and the longitudinal welded joint with the parallelogram model B has the lowest maximum tensile strain value of, 31.778 % based on the results of the tensile test.

Based on the results of the tensile test showed that the combination of the rectangular joint model combined with the type of welding direction (longitudinal-transverse) was the best model and had the highest tensile strength compared to the diamond model, parallelograms A and B combined with various types of welding directions. The results of this test also show that changes in the bolt position model and the direction of the weld have a clear effect on the tensile strength ratio. The results of this study provide a theoretical reference for the design of joint construction in determining the model for using a forward-bolt-welded combination.

The results of previous findings showed that the mechanic behavior of the bolt combination connection with the longitudinal welding process increases tensile strength but does not provide a simulation of the bolt position and the combination of longitudinal and transverse welding directions [1]. The discussion focuses on the interaction of bolts, welds, and plate joints that produce low residual stress with minimum angular deflection. Whereas, (Influence of Welding Sequence on Residual Stresses Induced in As-Welded Plug Weld of Low-Carbon Steel Plate.Pdf, n.d.) showed the results of the investigation of bolted and welded joints as a joint connection of the two parameters of the type of welding has a low residual tensile stress, due to the effect of distortion on the surface of the weld. Likewise, the connection model is used between bolts and welds with a variety of different types of bolts and the welding process as reinforcement in combination joints [17].

4. Conclusion

The results of tensile testing of bolted and welded combination joints from various models of bolt positions and types of welding directions given to affect the tensile strength of plate steel joints. The relationship between the bolt and weld combination system model shows that the square model bolt position with the longitudinal-transverse combination weld direction at a current strength of 140 Amperes is the best combined joint model with a maximum tensile strength of 347.222 MPa compared to the bolt position of the rhombic, parallelogram A and B models. The results of this test can be applied to building construction design, as well as being a reference for industries engaged in connection construction in the use of bolt position models and types of welding directions.

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