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Z.W. Zhu*, T. Qin, X.W. Chen
Preface

These proceedings contain the papers presented at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation—joined a few years later by the Hong Kong Institute of Steel Construction.

These proceedings bring together most recent findings in numerical, theoretical and experimental research, as well as its practical implementation in design practice in the areas of Assembled Structure, Bridge, Cold-formed Steel, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue, Fire, High-Strength Steel, Impact and Protection, Intelligent Construction, New Material, Seismic Resistance, Stability, Stainless Steel, Structure Systems, Testing & Monitoring. The papers presented in these proceedings come from a wide range of countries/regions and will be a great reference source.

Specially, the subject matter has been categorized under the broad heading of:

**Volume I:** Keynotes Lectures, Assembled Structure, Bridge, Cold-Formed, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue


Each of the papers was subjected to stringent review by a panel of experts in the respective area. This peer review began with an assessment of the submitted abstracts and following this, authors were invited to submit their full manuscripts. Each manuscript was then carefully reviewed by relevant experts, and their recommendations on accepting, rejecting or modifying the submissions were strictly adhered to, before inclusion in the conference proceedings.
Comparison of mechanical behavior between longitudinal lap-welded joints and transverse fillet welded joints of high strength steel

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Abstract: Mechanical behavior of twenty-eight longitudinal lap-welded joints made of high strength steels (HSS) under tension load was investigated by experimental study. Weaknesses due to traditional deformation measurements for fillet welded joints can be perfectly solved by digital image correlation techniques (DIC). The effect of parameters (e.g. weld size, weld length and mismatch ratio) on mechanical properties (e.g. ultimate strength, failure modes, weld ductility and fracture angle) of longitudinal fillet welds and transverse fillet welds, which was introduced in detail in previous work by the authors, were compared. Generally, because of the difference on the combination of shear force and tension force, the fracture angle of longitudinal welded specimens (around $50^\circ$) were much more divergent from transverse welded specimens (around $20^\circ$) even though both of them failed at welded zone (welded zone only refers to weld metal in this paper), resulting that the mean strength of longitudinal welded specimens were only 0.58 time of transverse welded specimens. Conversely, the mean deformation capacity of longitudinal welded specimens was almost 4.0 times of transverse welded specimens. Moreover, it was confirmed that the predicted loads of EC3 and AISC Specification were close and slightly conservative for all specimens.

Keywords: longitudinal welded joints; high strength steel; fillet welds; mismatch ratio; DIC technique

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1 INTRODUCTION

Because of the attractive strength-weight ratio, high strength steel (HSS, yield strength between 460 MPa and 960 MPa) have experienced respectable market share expansion in recent years. Thermal cycle within high strength steel while welding have critical influence on the chemical and metallurgical changes, which may affect the mechanical behavior. A series of studies on the performance of butt joints made of HSS [1-10] have been done in recent years. Due to the microstructure sensitive to the heat input energy, softened zone in heat affected zone (HAZ) was appeared and the strength loss was observed. Many designers and constructors expressed their concerns on adopting HSS in bridges and buildings.

For fillet welded joints, mechanical properties [11-16] and even strength criterion [17-19] have been studied and proposed successfully, but most of them were concentrated on mild steels with lower yield strength. Based on the strength criterion of mild steel, only Eurocode 3 Part 1-12[20] extends...
the design rules to cover the steel grades up to S700 and also allows the use of undermatched filler metals.

For the past few years, mechanical properties of fillet welded joints made of HSS under static loading \cite{21-28}, impact loading \cite{29, 30} and fatigue loading \cite{31-33} were investigated. Several novel conclusions different to mild steels have been achieved. For instance, predicted peak load by current design specifications \cite{20} is always conservative; Softened zone at weld toe has a harmful effect on the ultimate strength of load-carrying joints and non-loading-carrying joints; Increase of the grade of filler metal, the strength would increase slightly and the ductility would decrease.

No matter for mild steels or high strength steels, traditionally, the deformation capacity of the test weld was measured with potentiometers or transducers \cite{27, 34, 35}. Sometimes only strain gauges were used to measure elongation \cite{28}. Observing the setups and measured results, several obvious weaknesses were found: i) auxiliary devices were noticeably complicated (including wheels, bracket or cart \cite{35, 36}); ii) the transducers were always fallen off and broken easily with fracture occurred; iii) measuring accuracy was restricted because the total deformation was small; iv) effective test data was rare due to the contacted measurements. With the development of technology, digital image correlation (DIC) system, a non-contact technique, which can apply the information of displacements, strains, strain rates, velocities and curvatures along the whole loading process, was developed and used in testing system. The detailed working mechanism is presented in the user manual \cite{37}.

For mild steels, mechanical behaviours, especially load carrying capacity and deformation capacity, of longitudinal fillet welds and transverse fillet welds have major difference. For high strength steels, the research for longitudinal fillet welds and the comparison between transverse and longitudinal fillet welded joints were rare. Hence, the mechanical behaviour of longitudinal fillet joints of high strength steel was investigated in this paper by experimental and numerical studies. The comparison between two different fillet joints was conducted based on the data from DIC measurement.

2 EXPERIMENTAL INVESTIGATION

2.1 Material information

S690Q high strength steel plates and four corresponding grades electrodes were used to fabricate different longitudinal welds. To probe material properties, nine tension coupons of base metal and twelve tension coupons of weld metal (three for each metal) were tested, respectively. Table 1 and Table 2 summarize chemical composition and mechanical properties of materials used in this paper, exhibiting yield strength ($f_y^b$ or $f_y^w$), ultimate strength ($f_u^b$ or $f_u^w$), average hardness ($H_b$ or $H_w$), maximum elongation ($A_b$ or $A_w$) and ultimate strain $\varepsilon_u^w$ (i.e. the strain corresponding to the peak load).

<table>
<thead>
<tr>
<th>No.</th>
<th>Material</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>Nb</th>
<th>Ti</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Ni+Cu</th>
<th>CEV</th>
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</thead>
<tbody>
<tr>
<td>C1</td>
<td>10 mm plate</td>
<td>0.18</td>
<td>0.19</td>
<td>1.45</td>
<td>0.012</td>
<td>0.005</td>
<td>0.017</td>
<td>0.020</td>
<td>0.018</td>
<td>0.02</td>
<td>0.003</td>
<td>0.005</td>
<td>0.02</td>
<td>0.422</td>
</tr>
<tr>
<td>C2</td>
<td>20 mm plate</td>
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<td>0.25</td>
<td>1.24</td>
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<td>0.005</td>
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<td>0.020</td>
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<td>0.006</td>
<td>0.02</td>
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<tr>
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<td>30 mm plate</td>
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</tr>
<tr>
<td>F2</td>
<td>ER59-G</td>
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<td>0.71</td>
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<td>0.004</td>
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<td>0.28</td>
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### Table 2: Measured average mechanical properties

<table>
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<tr>
<th>No.</th>
<th>$f_y$ or $f_w$ [MPa]</th>
<th>$f_u$ or $f_{uw}$ [MPa]</th>
<th>$H_b$ or $H_w$ [Hv0.1]</th>
<th>$A_k$ or $A_v$ [%]</th>
<th>$\varepsilon_y$</th>
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<tr>
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<td>0.082</td>
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<td>192</td>
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<td>0.133</td>
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<td>F2</td>
<td>641</td>
<td>727</td>
<td>249</td>
<td>23.2</td>
<td>0.133</td>
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<td>F3</td>
<td>688</td>
<td>771</td>
<td>265</td>
<td>21.0</td>
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<td>F4</td>
<td>886</td>
<td>956</td>
<td>311</td>
<td>22.1</td>
<td>0.107</td>
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</table>

### 2.2 Specimen preparation

Specimen dimensions of fillet weld with longitudinal root notch was schematically illustrated in Figure 1. All specimens were fabricated by Gas Metal Arc Welding process (GMAW) with combination of 20% carbon dioxide (CO2) and 80% argon (Ar). Each specimen had test welds on one side (nominally 5 mm or 10 mm weld size) and reinforced welds on the other side to ensure failure on the test welds. In order to effective comparison between longitudinal fillet weld and transverse fillet weld, their welding procedures were the same. One welding pass was used for 5 mm weld size, while three passes were used for the 10 mm weld size, as indicated in Table 3.

For specimens with 60 mm, 90 mm and 120 mm weld length, test welds were machined to 5 mm weld size, whereas for specimens with 70 mm weld length, the predetermined size is 10 mm. Prior to testing, detailed measurements of the weld profile (e.g. horizontal shear leg (Shear leg_H), vertical shear leg (Shear leg_V) and bevel leg) and weld length were conducted, as shown in Figure 2.

![Figure 1: Key dimensions and fabrication details of longitudinal lap-welded specimens](image)

### Table 3: Welding parameters

<table>
<thead>
<tr>
<th></th>
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<td>5 mm</td>
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<td>240</td>
<td>27</td>
<td>2</td>
<td>350</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>240</td>
<td>27</td>
<td>2</td>
<td>350</td>
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</tr>
<tr>
<td>10 mm</td>
<td>2</td>
<td>250</td>
<td>27</td>
<td>2</td>
<td>320</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>250</td>
<td>27</td>
<td>2</td>
<td>320</td>
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</tbody>
</table>
2.3 Test setup and digital image correlation measurement (DIC measurement)

Twenty-eight longitudinal lap-welded specimens were tested quasi-statically in monotonic tension with a 2000 kN tensile capacity Materials Testing System (MTS) machine as shown in Figure 3. All tests were conducted in displacement control with 1.0 mm/min loading rate. Based on the calibration works by the authors [8] [38], DIC measurement performed excellently on recording the deformation of butt welded joints and transverse fillet welded joints. Detailed comparison between traditional measurements and DIC measurement was presented in the previous work [38].

3 EXPERIMENTAL RESULTS

3.1 Load and deformation capacity of longitudinal lap-welded specimens

Table 4 summarized the test results of loading capacity, deformation capacity, fracture angle and load deformation curve features of twenty-eight specimens. The naming scheme for specimen Lxy- z-n is as follows: L means longitudinal fillet welds. x refers to the grade of high strength steel, according to the naming rule of butt welded joints presented in the paper by the authors [8], S690Q.
steel is represented by C. y refers to the grade of electrodes, with 1, 2, 3 and 4 denoting F1, F2, F3 and F4, respectively. z refers to nominal weld length of the specimen, whereas 60, 70, 90 and 140 represent the nominal weld length of the specimen was 60 mm, 70 mm, 90mm and 140mm, respectively. n denotes the replicate number. For longitudinal lap-welded specimen, in order to load symmetrically, four test welds with identical dimension were machined, which were denoted as A-side, B-side, C-side and D-side, respectively (see Figure 2).

Representative load-deformation curves for longitudinal lap-welded specimens are shown in Figure 4. The loading capacity (peak load $P_u$ and fracture load $F_u$) and deformation capacity (the deformation corresponding to the peak load $\Delta_{P_u}$ and fracture load $\Delta_{F_u}$) of specimens were obtained from those curves.

Table 4: Test data from longitudinal lap-welded tension tests

<table>
<thead>
<tr>
<th>No.</th>
<th>$P_u$ [kN]</th>
<th>$F_u$ [kN]</th>
<th>$\frac{F_u}{P_u}$ [mm]</th>
<th>$\Delta_{P_u}$ [mm]</th>
<th>$\Delta_{F_u}$ [mm]</th>
<th>Fracture angle $^\circ$</th>
<th>Load-deformation curve feature</th>
<th>Test-to-predicted Ratio</th>
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<tbody>
<tr>
<td>A-side</td>
<td>B-side</td>
<td>C-side</td>
<td>D-side</td>
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<td></td>
<td></td>
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<td>LC1-60-1</td>
<td>409.9</td>
<td>363.6</td>
<td>0.89 1.594 2.980</td>
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<td>69.7</td>
<td>65.4 67.1</td>
<td>Platform</td>
</tr>
<tr>
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<td>422.9</td>
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<td>56.3</td>
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</tr>
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<td>LC3-60-1</td>
<td>440.4</td>
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<td>0.79 1.208 2.687</td>
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<td>66.8</td>
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</tr>
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<td>57.0</td>
<td>86.6</td>
<td>54.1 61.1</td>
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<td>LC4-60-1</td>
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<td>599.5</td>
<td>0.96 1.109 1.727</td>
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<td>0.94 1.057 1.467</td>
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<td>0.91 0.924 1.594</td>
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<td>0.94 0.474 1.059</td>
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<td>72.1</td>
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<td>51.4 40.3</td>
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<td>48.6</td>
<td>40.8</td>
<td>42.5 40.1</td>
<td>--</td>
</tr>
</tbody>
</table>

*Specimens were missing and there are no fracture information;

*Due to technique issues, whole or partial deformation information were not recorded by DIC measurement;
3.2 Measurement points selection using DIC measurement

Calculation region (blue area shown in Figure 5) was marked off and technically, the strain in every point and the relative displacement between every two points were recorded by DIC measurement, making the data extraordinarily abundant. For simplified analysis, several key points distributed in main plate, lap plate and welded zone were marked in Figure 5(a) and the displacement and strain development throughout the loading process of those key points were presented in Figure 6. Figure 6(a) exhibits that, in the same plate key points experienced similar displacement development, while in different plates key points had divergent displacement. Thus, relative displacement of arbitrary two points from different plates can represent the deformation of one-side fillet weld. In addition, all key points in base metal remained unyielded along the whole loading process (see Figure 6(b)), demonstrating that the deformation of base plate can be ignored.

Figure 5: Locations of key points at initial loading time (a) only single weld was measured (specimens with 5 mm weld size) and (b) double welds were measured (specimens with 10 mm weld size)

Since only one DIC measurement was used in the experiment, for specimens with 5 mm weld size, only one weld was measured, as shown in Figure 5(a), relative displacement DK (Key points D and K are in the middle of respective plate and they have the same height) was used as the deformation of the specimen. Typical load-deformation curves of longitudinal fillet welded
specimens were shown in Figure 4. In order to verify the rotation in plane, for specimens with 10 mm weld size, two welds were measured, as shown in Figure 5(b), key points D, K and N are in the different plate but with the same height. Relative displacement DK and NK were shown in Figure 4 (b). The marginal difference between those two curves (DK and NK) indicates that the rotation in plane can be ignored. Average deformation of DK and NK was used as the deformation of the specimen. Load-deformation curves of other specimens are displayed in Appendix III.

![Diagram](image)

Figure 6: (a) Displacement development and (b) strain development throughout the loading process of key points in longitudinal lap-welded specimen (e.g. LC1-60-1)

### 3.3 Strength of longitudinal lap-welded joints

The strength of longitudinal lap-welded joints is calculated referring to the following procedures:

- Step 1: determining ultimate load. Four test welds in a specimen were supposed to share the total ultimate load equally. Average load is denoted as $P$ (summarized in Table 4).
- Step 2: determining weld length. There are two weld lengths: one is nominal weld length, which is the distance from the end of lap plate to the end of main plate; another one is true weld length, which is the length of center line in welded zone due to the existence of run-in and run-out. Nominal weld length and true weld length are denoted as $l_e$ and $l_t$, respectively.
- Step 3: determining the height of failure surface. Similar to transverse fillet weld [38], technically there are two failure surfaces, i.e. theoretical throat surface and true fracture surface (see Figure 2). However, different from transverse fillet weld, whose fracture surface (around 20°) is much smaller than throat surface (around 45°), for longitudinal fillet weld, those two failure surfaces are similar (around 50° and 45°, respectively). Thus, only theoretical throat height ($h_{throat}$), which was defined as throat size before testing, was used to calculate the strength.
- Step 4: determining failure surface area. Calculation methods for failure surface area are two, i.e. $A_{throat,e} = h_{throat} \cdot l_e$ and $A_{throat,t} = h_{throat} \cdot l_t$.
- Step 5: determining ultimate strength. There are two definitions of ultimate strength, i.e. $P/A_{throat,e}$ and $P/A_{throat,t}$. Ultimate strength can be calculated when the specimen is designed. The results were summarized in Table 5.

Average deformation capacity of duplication specimens and average failure angle (measured from the shear leg) are summarized in Table 5. The effect of weld length and the grades of electrodes on the ultimate strength, deformation capacity and fracture angle of longitudinal fillet
weld are presented graphically in Figure 7 based on test data summarized in Table 5. Several observations were obtained:

1. Ultimate strength calculated by \( P/A_{throat, \text{le}} \) is always higher than the strength calculated by \( P/A_{throat, \text{lt}} \) because the true weld length \( l_t \) is always bigger than effective weld length \( l_e \).

2. Increase of the mismatch ratio (defined as the ratio between ultimate strength of weld metal to the ultimate strength of base metal) will improve the ultimate strength because failure location was in welded zone. As shown in Figure 8, X-axis represents relative weld strength (defined as the ratio between the ultimate strength of filler metals to the ultimate strength of filler ER50-6) and Y-axis stands for relative joint strength (defined as the ratio between the strength of longitudinal fillet welded joints to the strength of longitudinal fillet welded joints made of ER50-6 and the strength was calculated by \( P/A_{throat, \text{le}} \)). It demonstrates clearly that with the increase of the strength of filler metal, the strength of fillet welded joints will increase almost linearly. However, the increase rate of joint strength is lower than the speed of weld strength.

3. For specimens with the same weld size, increase of weld length would slightly increase the ultimate strength.

4. Ultimate strength of specimens were between the shear strength and the tensile strength of filler metals, indicating that specimens were loaded under the combination of both shearing force and axial force.

5. Both weld length and the strength of filler metal have negative effect on the deformation capacity of longitudinal fillet welded joints.

6. Effect of weld size on the strength and deformation capacity of specimens were marginal, while it had obvious effect on fracture angle. Fracture angle were around 45° for specimens with 10 mm weld size, whereas fracture were around 50° for specimens with 5 mm weld size and the variability was larger.

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Filler Metal</th>
<th>Mean Ultimate Load for One-side ( r ) [kN]</th>
<th>( P/A_{throat, \text{le}} ) [MPa]</th>
<th>( P/A_{throat, \text{lt}} ) [MPa]</th>
<th>Mean ( \Delta \gamma ) [mm]</th>
<th>Mean ( \Delta \gamma ) [mm]</th>
<th>Mean Fracture Angle [°]</th>
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</thead>
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<tr>
<td>LC1-60</td>
<td>ER50-6</td>
<td>104.1</td>
<td>436.7</td>
<td>392.6</td>
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<td>ER76-G</td>
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<td>433.5</td>
<td>1.110</td>
<td>2.254</td>
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</tr>
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<td>ER96-G</td>
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<td>338.4</td>
<td>554.5</td>
<td>538.7</td>
<td>0.823</td>
<td>1.480</td>
<td>51.0</td>
</tr>
<tr>
<td>LC2-140</td>
<td>ER59-G</td>
<td>389.3</td>
<td>706.1</td>
<td>682.4</td>
<td>0.466</td>
<td>1.511</td>
<td>49.8</td>
</tr>
<tr>
<td>LC3-140</td>
<td>ER76-G</td>
<td>360.5</td>
<td>629.3</td>
<td>605.8</td>
<td>0.461</td>
<td>1.078</td>
<td>54.8</td>
</tr>
<tr>
<td>LC4-140</td>
<td>ER96-G</td>
<td>419.9</td>
<td>733.6</td>
<td>715.2</td>
<td>0.252</td>
<td>0.405</td>
<td>43.3</td>
</tr>
</tbody>
</table>

*Specimens were missing and there are no fracture information;
4 Experimental analysis

4.1 Comparison between longitudinal fillet welds and transverse fillet welds

Twenty-eight longitudinal lap-welded specimens and forty-four transverse lap-welded specimens (including twenty-four transverse lap-welded joints and twenty cruciform type joints)
were tested by the authors. In this section, mechanical behaviors of those three kinds of fillet welded joints were compared. Brief comparison results was summarized in Table 6 and the results will be discussed in detail at the subsection below.

Table 6: comparison on mechanical behaviour of three kinds of fillet welded joints

<table>
<thead>
<tr>
<th>Joint types</th>
<th>Failure mode*</th>
<th>Failure location</th>
<th>Relative strength</th>
<th>Deformation (mm)</th>
<th>Fracture angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse lap-welded specimen</td>
<td>Double/Single</td>
<td>Welded zone</td>
<td>1.00</td>
<td>0.4~1</td>
<td>13~23</td>
</tr>
<tr>
<td>Cruciform type transverse specimen</td>
<td>Double</td>
<td>Fusion line</td>
<td>0.82</td>
<td>0.4~1</td>
<td>14~28</td>
</tr>
<tr>
<td>Longitudinal lap-welded specimen</td>
<td>Four sides</td>
<td>Welded zone</td>
<td>0.58</td>
<td>1~4</td>
<td>42~66</td>
</tr>
</tbody>
</table>

4.1.1 Failure modes

Except for specimens failing in base metal due to oversize weld leg, the failure location for longitudinal lap-welded joints and transverse lap-welded joints was in welded zone. For cruciform type specimen, due to softening and other metallurgical effects, fusion line area may be weaker than the adjacent base metal and filler metal. As shown in Figure 9(c), the fracture location of cruciform type specimens are more likely to lie on fusion line area.

![Failure modes](image)

(a) Four sides failure together (longitudinal lap-welded joints)  
(b) Single side failure in advance (transverse lap-welded joints)  
(c) double sides failure together (cruciform type specimens)

Figure 9: Typical failure modes of three fillet welds

4.1.2 Ultimate strength

![Ultimate strength](image)

Figure 10: Ultimate strength comparison of three kinds of fillet welded joints

Figure 10 shows the comparison of the ultimate strength among three kinds of fillet welded joints. The strength distribution of transverse fillet welded joints is more concentrated than that of longitudinal fillet welded joints. The tensile strength of the specimens when the loading direction is perpendicular to welding direction (i.e. transverse fillet welded joints) is higher than specimens.
when the loading direction is parallel to welding direction (i.e. longitudinal fillet welded joints). Both normal stress and shear stress existed on the fracture surface of transverse fillet welded joins, while there is almost only shear stress on the fracture surface of longitudinal fillet welded joints. The ultimate strength of longitudinal fillet welded joints is around 0.58 time of the strength of transverse fillet welded joints.

4.1.3 Deformation capacity

According with mild steel, for high strength steels, the deformation capacity of longitudinal fillet welded joints (1-4mm) is larger than transverse fillet welded joints (<1mm). In order to eliminate the scale effect, Figure 11 demonstrates load-displacement curves of three types fillet welded joints with the same weld size, the same weld length and the same filler metal. It indicates that the deformation capacity of longitudinal fillet welded joints is higher than that of transverse fillet welded joints. In addition, for transverse fillet welded specimens, the fracture occurred suddenly and the failure behaviour is more like brittle failure, while the failure for longitudinal fillet welded joints are more like ductile failure.

![Deformation capacity comparison of three kinds of fillet welded joints](image-url)

Figure 11: Deformation capacity comparison of three kinds of fillet welded joints (a) weld metal: ER50-6, weld size: 10mm, weld length: 70mm; (b) weld metal: ER76-G, weld size: 10mm, weld length: 70mm

4.1.4 Fracture angle

To study the mechanical behavior of fillet welded joints, the procedure for determining fracture angle was essential. After the fracture angle was determined, the area of fracture surface could be obtained and then the load carrying capacity could be achieved. Theoretically, the failure surface would lie on the smallest surface (45°). However, since the resultant stress of normal stress and shear stress in the smallest surface is not the highest, making the smallest surface not the dangerous surface. Especially for transverse fillet welded joints, as shown in Figure 12, the fracture angle was around 20°. Several conclusions can be obtained from Figure 12:

1) The average fracture angle for transverse lap-welded joints, cruciform type specimens and longitudinal lap-welded joints are 20.1°, 18.5° and 51.5°, respectively. Fracture angle of two kinds of transverse fillet welded joints are similar and mainly concentrates in 15°-25°, while the fracture angle distribution of longitudinal lap-welded joints is dispersive (from 40° to 70°).

2) Filler material has no effect on the fracture angle.
3) One of the reasons that the strength of transverse fillet welded joints higher than longitudinal fillet welded joints is that the fracture surface of the latter is closer to the theoretical fracture surface.

In order to observe the fracture angle directly, with the aid of DIC measurement, the strain distribution contours right before failure were shown in Figure 13. The fracture angle of transverse fillet welded joints is obvious less than \(45^\circ\), while the fracture angle of longitudinal fillet welded joints is approximately at the diagonal line.

5 COMPARISON WITH CURRENT DESIGN EQUATIONS

Design resistance of fillet welded joints according to Eurocode 3 Part 1-12\(^{[20]}\) (EC3) and North American standard AISC Specification \(^{[39]}\) (AISC) are expressed by functions (1) and (2), respectively.

\[
F_{EC3} = \frac{f_{yw} / \sqrt{3}}{\beta_w A_w M_2} A_e
\]  

(1)
where $f_u$ is the ultimate strength of filler metal; $A_e$ is the theoretical throat area; $\beta$ is correlation factor and for high strength steel it is taken as 1.0; $\gamma_{M2}$ is partial safety factor. $\phi$ is resistance factor; $\theta$ is the angle between loading direction and the weld axis, and $\theta$ is taken as 0° for longitudinal fillet joints. In order to obtain an objective comparison, safety factor $\gamma_{M2}$ in Eq.(1) and resistance factor $\phi$ in Eq.(2) were taken as 1.0.

Table 4 summarized the test-to-predicted ratios of each specimen. No matter predicted value by EC3 or by AISC, the test-to-predicted ratios are always greater than 1.0 in all cases. Figure 14 (a) and (b) exhibit comparison between the test results and predicted values of EC3 and AISC, respectively. As shown in Figure 14, diagonal lines indicate that the test-to-predicted value is 1.0. All test results lie on the conservative side. The test-to-predicted ratios by EC3 vary from 1.0 to 1.69 (mean value is 1.33), while the test-to-predicted ratios by AISC vary from 0.97 to 1.62 (mean value is 1.28). For EC3 and AISC, the strength of filler metals has no effect on the test-to-predicted ratio, while weld length seems have positive effect on test-to-predicted ratio. Besides, test-to-predicted ratios of current design equations for longitudinal lap-welded joints are more reasonable than transverse lap-welded joints (mean value is 2.01)[38].

Figure 14: Test vs. predicted capacity by (a) EC3 and (b) AISC

6 SUMMARY

Twenty-eight experimental tests were carried out for longitudinal fillet welded joints made of S690Q high strength steel. Four classifications of filler metal, namely ER50-6, ER59-G, ER76-G and ER96-G were used. All the filler metals are deposited using the GMAW process. Two nominal weld sizes (5 mm and 10 mm) and four weld lengths (60, 70, 90 and 140 mm) were included in each mismatch-type of longitudinal fillet welded specimens. Based on the mechanical tests and digital image correlation technique, the following observations and conclusions are made:

- Failure location for longitudinal lap-welded joints and transverse lap-welded joints was in welded zone. For cruciform type specimen, due to softening and other metallurgical effects, the fracture location of cruciform type specimens are more likely to lie on fusion line area. The average fracture angle for transverse lap-welded joints, cruciform type specimens and longitudinal lap-welded joints are 20.1°, 18.5° and 51.5°, respectively.
The tensile strength of the specimens when the loading direction is perpendicular to welding direction (i.e. transverse fillet welded joints) is higher than specimens when the loading direction is parallel to welding direction (i.e. longitudinal fillet welded joints). The ultimate strength of longitudinal fillet welded joints is around 0.58 time of the strength of transverse fillet welded joints.

Accordance with mild steel, for high strength steels, the deformation capacity of longitudinal fillet welded joints (1-4mm) is larger than transverse fillet welded joints (<1mm). In addition, for transverse fillet welded specimens, the fracture occurred suddenly and the failure behaviour is more like brittle failure, while the failure for longitudinal fillet welded joints are more like ductile failure.

It is confirmed that EC3 and AISC Specification are conservative for all mismatched filler metals. The test-to-predicted ratio ranges from 1.0 to 1.69 (mean value is 1.33) and 0.97 to 1.62 (mean value is 1.28) for EC3 and AISC Specification, respectively.

References


These proceedings contain the papers at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation - joined a few years later by the Hong Kong Institute of Steel Construction.

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