Abstract: The paper summarizes an extensive experimental program aiming to evaluate strength and ductility performance of welded connections between high strength and mild carbon steel components. These connections are components of moment resisting beam-to-column joints in dual-steel building frames. Welded joint components are of High Strength Steel (HSS) and Mild Carbon Steel (MCS). In this paper, test results on different weld details, used to connect HSS with MCS components are presented and analyzed.

Key-Words: dual steel welded connection, high strength steel, monotonic, cyclic loading

1 Introduction

Previous studies realized by authors (Dubina and Dinu, 2007, Dubina et al., in print) showed the advantages of using High Strength Steel (HSS) in combination with Mild Carbon Steel (MCS) in so called Dual-Steel Structures (DSS), to enhance robustness and better control of the response of seismic resistant building frames.

To get a rational design of a seismic resistant structure – i.e. both safe and economic – the dissipative elements have to approach the plastic capacity under design forces, in order to reduce the demand on non-dissipative members. The best way to accomplish this is not by changing size of sections in dissipative and non-dissipative members because it also changes their stiffness, but to realize them of MCS and HSS, correspondingly. Such a DSS system, if properly designed to obtain a good balance between stiffness, strength and ductility of members and connections, enables to achieve the three critical tasks of a seismically robust structure i.e.: (1) secure plastic deformations in structural members targeted as dissipative; (2) prepare multiple routes for transfer of forces and ensure their redistribution through yielding of other members; (3) provide sufficient overstrength to structural members that are not allowed to yield.

In a DSS system, MCS members have to behave like fuses, dissipating the seismic energy through plastic deformation, while HSS members have to remain predominantly elastic, or with limited damage, being responsible for robustness of the structure. This principle applies both, for members and joint components. In case of moment resisting frames designed according to the strong column - weak beam philosophy, the columns are usually designed to remain predominantly elastic during earthquakes, while the beams have to be ductile. For welded beam-to-column joints, the main contributors for ductility are column web in shear and the beam end, while for extended end-plate bolted connection, beside the beam end and the column web, the end-plate in bending becomes very important.

Starting from the above considerations, a large experimental research program was carried out at the "Politehnica" University of Timisoara, CEMSIG Research Centre (http://cemsig.ct.upt.ro) in order to study the performance of dual-steel configuration for beam-to-column joints under monotonic and cyclic loading. When HSS is used in members designed to remain predominantly elastic, as columns, for instance, or in end-plates of bolted joints, welded components made of two steel grades are obtained. The aim of the testing program which is summarized hereafter was to investigate experimentally the performance of welded connections realized from two different steel grades. A full description of whole testing program can be found in References ([1], [2], [3]), in which both test results and their interpretation is presented. In the actual paper, tests on weld details are particularly presented.
2 DESCRIPTION OF THE TESTING PROGRAM

The objective of the experimental program was to study the performance of welded and bolted end-plate beam to column joints realized from two different steel grades. The experimental program consisted in tests on materials, welded components, T-stub components, and beam to column joints. This paper describes only the investigations performed on materials and welded components.

Standard tensile and Charpy V-notch toughness tests were performed in order to determine mechanical characteristics of base materials and welded material. Welded details (see Table 1) were considered in order to reproduce the welded connection between beam flange and column flange, as well as the one between the beam flange and end-plate. The web was always S235, while the end-plate was realized from S235, S460 and S690 steel grades. Both fillet welds and three types of full-penetration welds were used. Tests were performed under monotonic and pulsating cyclic loading. Tests on welded details were performed in order to validate the welding technology and to investigate performance of welded connections when realized from steel of different grades.

MAG welding was used, with G3Si1 (EN 440) electrodes for S235 to S235 welds, and ER 100S-G/AWS A5.28 (LNM Moniva) for S235 to S460 and S690 welds. Loading was applied in displacement control under tension and force control under compression. Compressive force was chosen so as to prevent buckling of the specimen.

3 TEST RESULTS

3.1 Materials
Flat materials used for welds details were supplied by UNIONOCEL, Czech Republic. Table 2 shows the measured average values of yield stress $f_y$, tensile strength $f_u$ and elongation at rupture $A$. It has to be recognize that the value of elongation for S460 is surprisingly large. Bolts were tested in tension as well, showing an average ultimate strength of 862.6 N/mm².

Table 1. Summary of testing program

<table>
<thead>
<tr>
<th>Test type</th>
<th>Scheme and steel grades</th>
<th>Test characteristics</th>
<th>No. of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Per type</td>
</tr>
<tr>
<td>Materials (MAT):</td>
<td>S235, S460, S690</td>
<td>monotonic quasi-static tensile tests</td>
<td>3</td>
</tr>
<tr>
<td>Base and weld</td>
<td></td>
<td>Charpy V-notch toughness tests (-20°C)</td>
<td>3</td>
</tr>
<tr>
<td>Welded connections (SUD)</td>
<td>web and stiffeners:</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>S235, t = 15 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>end-plate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S235, t = 20 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S460, t = 15 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S690, t = 12 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Weld type:
- fillet weld
- 1/2V bevel weld without root rewelding
- 1/2V bevel weld with root rewelding
- K bevel weld

Type of loading:
- monotonic quasi-static
- cyclic quasi-static

Table 2. Material properties

<table>
<thead>
<tr>
<th>Nominal steel grade</th>
<th>$f_y$, N/mm²</th>
<th>$f_u$, N/mm²</th>
<th>$A$, %</th>
<th>Actual steel grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>S235</td>
<td>266</td>
<td>414</td>
<td>38</td>
<td>S235</td>
</tr>
<tr>
<td>S460</td>
<td>458</td>
<td>545</td>
<td>25</td>
<td>S460</td>
</tr>
<tr>
<td>S690</td>
<td>831</td>
<td>859</td>
<td>13</td>
<td>S690</td>
</tr>
</tbody>
</table>
3.2 Weld details
Tests on weld details were performed in order to assess the performance of welds connecting different steel grades and to validate the welding technology. Weld preparation and the technology for \( \frac{1}{2} \) V bevel weld, for instance, is shown in Figure 1. Welds have been made at ISIM- National R&D Institute for Welding and Material Testing. Sample of some weld experimental force-displacement are shown in Figure 3 to 6, while Figure 8 shows the state of strain in the area of the weld and the Heat Affected Zone (HAZ). In fact, since the weaker material was S235 in the "web", there are no significant differences in terms of steel grades of "end-plate". It has to be noticed that all the welds proved a very good behavior with failure at the end of HAZ or in vicinity, as expected. So, both the choice of welding materials and technology were confirmed. Pulsating cyclic loading did not affect much the response in comparison with monotonic loading.

![Welding technology](image1)

**Figure 1. Welding technology**

<table>
<thead>
<tr>
<th>Welding pass</th>
<th>Welding procedure</th>
<th>Type and dimension for added material (mm)</th>
<th>Voltage and polarity (A)</th>
<th>Voltage (V)</th>
<th>Avans speed (m/min)</th>
<th>Welding speed (cm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>135</td>
<td>ER 100S-G/AWS A5.28-96/ FILCORD TENAX S Φ 1.2</td>
<td>300/DC⁺</td>
<td>29.5</td>
<td>9.5</td>
<td>42</td>
</tr>
</tbody>
</table>

3.3 Testing set-up
Laboratory test have been performed using displacement transducers (3pieces), force transducer (1piece), and optical measurement system Vic3D. The optical measurement system allowed us to measure deformation and stresses in the same time. Testing set-up can be easily seen in the left figure.
### 3.4 Results and interpretation

![Graph 1: Comparison and classification of weld detail test results in regard with steel grades (monotonic loading)](image1)

![Graph 2: Comparison and classification of weld detail test results in regard with weld details (monotonic loading)](image2)

*Fig 3: Comparison and classification of weld detail test results in regard with steel grades (monotonic loading)*

*Fig 4: Comparison and classification of weld detail test results in regard with weld details (monotonic loading)*
Fig 5 Comparison and classification of weld detail test results in regard with weld details and type of loading (monotonic vs. cyclic loading)

Fig 6 Comparison and classification of weld detail test results in regard with weld details and type of loading (monotonic vs. cyclic loading)
Figure 7. Test results on welded specimens: fillet welds on cyclic loading and mode of failure (a); double bevel welds and mode of failure (b); Fillet welds on monotonic loading and failure mode (c)
Fractography proves a ductile failure mode far all specimens, even if in some cases intergranular brittle micro-failures were observed.

4 Conclusion
Welds between different steel grades performed adequately under monotonic and cyclic loading. All tests proved a very good behavior of welded connections. For each type of weld detail (fillet, K, 1/2V bevel weld), and all combinations of base materials (S235, S460, S690), the connections failed in base material, and not at welded point. No significant difference between monotonic and cyclic loading was observed in terms of strength and weld failure mode. Requested strength and ductility performances of welded connections between high strength steel and mild carbon steel components were confirmed.
References:


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