Description of Work

Task 5.2: Topical Investigations on Joining and Inspection

Sub-Task 5.2.2 – Assess the effects of weld metal and heat affected zone notch toughness on welded joint behavior considering different defects/imperfections and strain rates

Background:

Please see the attached document "Overview of Topical Investigations on Joining and Inspection" for the technical background to this sub-task and the relationship between this sub-task and the other Joining and Inspection sub-tasks and the overall Phase 2 project.

Objectives of Sub-task

Efforts will be undertaken in this sub-task to assess the effects of weld notch toughness on the behavior of simple welded joints considering different defects/discontinuities and strain rates. This information will be used to help identify desirable toughness-related properties for FCAW-SS welded joints in steel moment-resisting frame connections subject to different strain rates and stress levels. Tests will be used to assess that ability to predict joint fracture behavior on the basis of the character of defects present, and knowledge of material and fracture toughness properties. Data will be interpreted to help establish estimates of the strength, deformability and failure mode of welded joints as a function of toughness-related material properties for the base and weld metal, load (stress) intensity and strain rate.

Description of Sub-task

The level of loading applied during a seismic event greatly exceeds the expected service loading levels in most structures, and the required weld quality acceptance criteria for these types of applications has not been definitively established at this time. The required quality level is a function of the level of loading (expected behavior under intended use), the toughness of the weld metal and heat affected zone, the discontinuities (location, type, size and distribution) present in the base materials and welds, and the presence of local details that act as stress concentrations. Acceptance criteria will be established for three levels of loading (low, medium and high), as well as three different toughness levels (low, medium and high). The data obtained in the investigation will be used in Sub-task 5.2.6 along with other information to establish the acceptance criteria for the welds in welded steel moment-resisting frames.

The effort in this sub-task supplements the activities in 5.2.1, and requires close coordination in selecting, fabricating, inspecting, and testing the specimens. In this subtask, two basic types of specimens are utilized. The first type of tests (both CVN and CTOD) will include basic fracture and material properties. The second is a "welded plate" specimen like that shown in Fig. 1 containing a single bevel CJP weld where failure is initiated in the weld region by selecting a suitable loading condition or by machining a small notch in the surface of the weld. Tests may be performed in tension, but three point bending or other tests may be used with the approval of the Project Director for Topical Investigations. In addition to relatively defect-free test plates, other welded plates with introduced defects will be tested at specified deformation rates to correlate toughness-related material properties and defect characteristics, with basic fracture mechanics principles. These simulated imperfections may represent defects that may not be reliably detected using current UT technology.

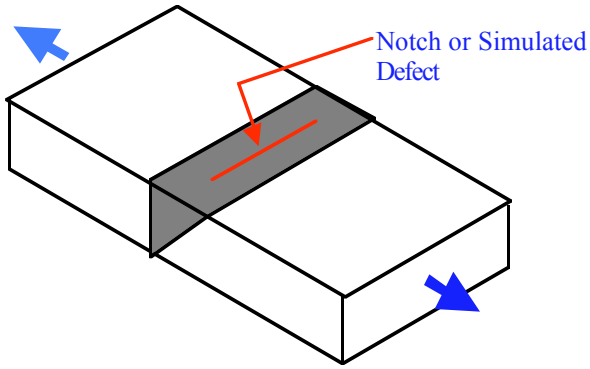

Fig. 1 – Simple Welded-Plate Specimen

Basic considerations in designing, constructing and testing the fracture toughness and "welded plate" specimens include the following:

- It is intended in this sub-task that the material used for the base metal should have metallurgical and other properties similar to those utilized in building construction. This material should in general be similar or identical to that used in Sub-task 5.2.1 for the beam flange material in the T-Stub test specimens. Care should be taken in these tests to ensure that the longitudinal (rolling) direction of the base metal is oriented perpendicular to the weld. Plates used in this sub-task will be flanges extracted from existing beams, because thick plates with chemical composition equivalent to structural shapes are not available.

- Sizes of plate material used to represent the beam flange should result in flange thicknesses of at least 1 inch and a width of approximately six inches, and be selected in coordination with sizes used in the through-thickness property and other joining tests (Sub-tasks 5.1.2, 5.2.1, and 5.2.3) as well as in the subassemblage tests in Task 7.

- A range of strengths are to be utilized in Sub-task 5.2.1 for the beam and weld to replicate overmatching, undermatching and matching strength conditions. Three base metal (beam flange) strengths and three weld metal strengths are to be selected. The column will be chosen to have a strength sufficient to cause failure to occur in the weld region or in the beam flange. In existing buildings, situations may occur where the strength of the weld filler undermatches that of the base material. Recent analyses suggest potential benefits of having the weld filler material overmatch the strength of the base metal by a significant margin.

- The first test matrix for this subtask will include nine combinations of beam base materials and weld strengths as utilized in sub-task 5.2.1. In the first set of these tests, welding procedures similar to those used in sub-task 5.2.1 will be employed. A sub-set of tests will then be explored, using weld filler material having similar strength, but lower notch toughness, and higher notch toughness. The sub-contractor shall develop the test matrix for fabricating specimens with similar weld region strength and targeted notch toughness with the Technical Advisory Panel and approval by the Project Director for Topical Investigations.

- The second test matrix for this subtask will include a small number of selected "welded plate" specimens as shown in Fig. 1. Failure of these specimens will be initiated in the weld region by machining a small notch in the surface of the weld. Tests may be performed in tension, but three point bending or other tests may be used with the approval of the Project Director for Topical Investigations.

- One or more benchmark specimens will be designated in this test series having similar characteristics related to material strength, welding procedures, member sizes and so on as those utilized in the various investigations undertaken in Sub-tasks 5.1.2, 5.2.1, and 5.2.3 as well as in the subassemblage tests in Task 7. These benchmarks will be established in coordination with the Project Director for Topical Investigations.

- The detail utilized by the sub-contractor for the CJP weld is to be approved by the Project Director for Topical Investigations including impact toughness and other characteristics of the consumables, the welding procedure specifications, and the method for removal of the backing and repair of the root pass.

- It is desired that the welds and materials be essentially free of defects or discontinuities that would significantly contribute to the failure (see acceptance standards stipulated below). Thus, thorough NDE of the welds and materials (and documentation of results) is required prior to load testing. The weld region should satisfy the requirements of AWS D1.5 for fracture critical welds.

CVN and CTOD tests will be performed on the butt welded plate specimens. It is envisioned that each set of these welded plate and toughness specimens will be machined from a single long welded plate in order to simplify fabrication and help assure constant properties in the weld region. A complete toughness-testing temperature curve will be generated for each of the beam flange-filler metal combinations. Correspondingly, CTOD curves will also be determined for those same material combinations. If new base materials are used (including the use of a different heat) than used in another sub-task for which mechanical properties (stress-strain, hardness and toughness characteristics) have been previously obtained, tests will also be conducted to fully characterize the unidirectional strength properties in longitudinal, transverse and through thickness directions of these materials. In an attempt to extrapolate data for larger scale specimens, several plate specimens with EDM induced defects will be used. The fracture toughness data will be correlated with the fracture behavior of the weld plates with induced defects.

To facilitate comparison of results, and minimize the efforts needed to conduct material tests, efforts should also be made to coordinate fabrication and inspection of specimens to be used in different parts of this project (e.g., Sub-tasks 5.1.2, 5.2.1, 5.2.3 and so on). Ideally, specimens in different sub-tasks having matched base metal and weld properties would be fabricated from the same heat of steel stock and welding consumables and utilize the same welder and inspectors.

Efforts will be undertaken to compare and correlate results obtained in these two types of tests, including analysis of the microstructure, chemical composition, fracture surface and so on. The controlling toughness-related parameters as affecting joint performance will be determined through these experiments considering the size of defect that can be reliably identified using current UT technology.

The data obtained in Sub-task 5.2.2 will be used to help establish the weld quality acceptance criteria for steel moment resisting frames in Sub-task 5.2.6. As noted previously, in some circumstances, conditions of use may result in the weld having only to develop a specified strength (essentially elastic behavior) so that the plastic hinge can develop at another location; in other situations, the weld region may have to contribute significantly to the overall plastic deformation capacity of the connection; in still other conditions, behavior of the welded region may be affected by the need to develop substantial yielding in the beam material immediately adjacent to the weld.

Scope of Work

To achieve the objectives of the subtask the sub-contractor is expected to develop and submit for approval to the Project Director for Product Development a detailed Sub-task Work Plan addressing the objectives of the sub-task. It is anticipated that this Work Plan will include, among others, the following items:

1. The contractor must attend necessary meetings during the period of the sub-contract (e.g., project kickoff and quarterly team meetings with the Project Director of Topical Investigations and the Technical Advisory Panel). The sub-contractor is expected to provide regular verbal and written reports to the Team leader for Joining and Inspection and to the Project Director for Topical Investigations and be responsive to their requests related to the work.

2. The welding shall be performed by an experienced welder, qualified in accordance with AWS D 1.1 for each electrode used. Inspectors shall likewise be experienced and qualified to inspect fracture critical welds according to AWS D1.5.

3. Based upon the initial results obtained from Sub-task 5.2.1, an experimental matrix of fracture toughness tests (both impact toughness and CTOD) will be established by the sub-contractor for the determination of toughness-related properties of welds as a function of testing temperature, base metal (beam flange) and weld metal. A second experimental matrix will consist of testing selected weld plates with induced defects. The sub-contractor will also recommend for the consideration and approval of the Project Director for Topical Investigations loading histories, testing temperature(s) for the welded plate and impact toughness specimens, instrumentation, methods for inducing failure/fracture in the weld (e.g. wire electrical discharge machining), characteristics of induced defects region (including likely crack geometry, dimension and location), and so on. The sub-contractor shall identify the number and anticipated types of tests to be undertaken in Item 9 below such that this effort will help in achieving the objective of the sub-task.

4. Nine sets of multipass weld tension plate and fracture test specimens will be prepared using the welding parameters determined in Task 5.2.1. These nine specimens correspond to the combinations of the three beam flange materials and three (notch-tough) filler metal strengths used in that sub-task. Thus, nine tension plate specimens are to be fabricated along with the corresponding CVN and CTOD toughness test specimens. The sub-contractor must see to it that the specimens are manufactured in strict conformance with the approved specimen designs and welding procedure specifications, as well as the stipulated inspection and acceptance criteria. The welds will be inspected using ultrasonic testing techniques to determine the quality of the joint. All inspection records must be presented for the final reporting of the program. For acceptance, welds must satisfy criteria in AWS D1.5 for fracture critical welds. While weld repair is allowed in the preparation of these specimens, the finished weldment must meet QA and QC requirements according to AWS D1.5-95 Section 12.17 on Critical Weld Repair.

5. For the weld specimens prepared for extraction of CVN and CTOD specimens, no intentional defect will be introduced. The specimens will be tested to determine the level of toughness and the nature of the failure. A minimum of four testing temperatures (-30, 0, 32, and 70^{o}F) should be used to characterize each toughness-testing temperature curve. Correlation between CVN and CTOD test results will also be carried out.

6. Selected weld specimens (a minimum of three) will be identified from the matrix for further testing using specimens with intentional defects induced at the surface in the weld region. It is suggested that a defect of a given a/2c ratio, i.e. crack depth/crack length ratio, be introduced using the electrical discharge machining (EDM) process. A crack of 0.3 in. deep and an a/2c ratio of 0.25 can be considered as the starting point. The characteristics of the defect must be approved by the Project Director for Topical Investigations.

7. Loading of the weld specimens in item 6 will be applied to the welded plate specimens at a loading rate comparable to seismic conditions, e.g. 1 to 2 seconds to failure, and at a selected baseline temperature (e.g. 0^{o}F). The specimens will be examined to determine the level of fracture strength and the nature of the fracture. The stress level and fracture appearance will be recorded for correlation.

8. Again, those specimens from item 7 that are characterized as having failed in a ductile fashion will be re-tested at the same temperature. New weldments will be produced with a single intentional defect twice the size of the ones introduced the first time. The a/2c ratio, however, will be maintained. An induced internal defect might be considered as an alternative to two surface defects. The location of the defect must be approved by the Project Director for Topical Investigations.

9. Those specimens (from item 8) failing in a brittle fashion will be tested at a slower rate to establish sensitivity to strain rate and defects. The baseline temperature will be maintained for the tests.

10. Additional impact toughness data will be gathered for some of the welded plate specimens considered in the items 4 and 5. In particular, CVN specimens will be extracted from: (a) a region in the weld metal close to the root pass, (b) a region in the weld metal close to the face of the weld, and (c) two locations within the heat affected zone(s) (e.g. the coarse grained HAZ and the intercritical HAZ as identified by micro-etching). Three different temperatures (-30, 0, 32, and 70^{o}F) will be utilized for these impact toughness tests. Chemical analyses will also be performed to characterize the weld

material. The tests in this item need not be done, if such tests have been performed on identical specimens as part of other sub-tasks.

11. The impact toughness of the specimens will be examined, documented and correlated with the base metal/filler metal strength data, as well as with analyses based on tension plate specimens and the application of fracture mechanics principles.

12. Preliminary test and analysis results are to be supplied to other investigators working within the Phase 2 project. Regular and prompt communication of results to investigators working on other sub-tasks in Task 5.2 is expected. Test specimens are to be archived for at least 3 months following the conclusion of the sub-contract and made available to other investigators as requested. Fracture surfaces are to preserved using a suitable protective coating.

A final report outlining the test methodology, test results, analysis of the results including analysis of the fracture surface, comparison between the large-scale and small-scale fracture tests will be prepared.

Task Management and Review

This subtask is supervised by James Malley, Project Director for Topical Investigations. The Joining and Inspection Technical Advisory Panel (TAP) will provide oversight and an advisory role on the conduct of the research and will review and evaluate reports and recommendations. The Team Leaders and selected members of the Materials and Fracture TAP and the Connection Performance TAP, as well as the Guideline Writers for In-Process Inspection, New Construction, and Repair will also review and evaluate this work. It is expected that the subcontractor/consultant selected for this task will be responsive to issues and concerns raised by the Project Director, TAP and other reviewers.

Target Audience

The work products of this task will be directly used by consultants and sub-contractors working on the SAC Phase 2 project. The general results and the interpretation of these results will be of interest to Topical Investigation Team Leaders for Materials and Fracture and Connection Performance, as well as Guideline Writers and other general users.

Sub-Task Deliverables

Subcontractor will submit the following items as deliverables:

1. Revised and detailed work plan based on kick-off meeting discussions.

2. Completed experimental weld matrix and testing protocol as outlined in the work plan.

3. Results of completed inspection to ascertain the acceptability of the test specimens, as well as changes in inspection indications occurring as a result of testing.

4. Completed impact toughness testing to determine the relative Charpy absorbed energies at different temperature and different base-weld metal combinations.

5. Completed CTOD testing to determine the relative fracture energies at different temperature and different base-weld metal combinations.

6. Completed microstructural analysis and mechanical testing of the welds performed to determine the effect of base metal and filler metal on weld performance.

7. Completed large weld plate testing with induced defects to determine the failure conditions specific testing temperatures and loading conditions.

8. Regular progress reports and updates.

9. Final report on the results of the sub-task, including necessary revisions required by the Technical Advisory Panel and Project Director for Topical Investigations. Numerical data and photographic documentation of the test results shall also be provided.

Format requirements for submission of reports and data are to be specified by the Project Director for Topical Investigations.