Technical Note:
Abrasive Water Jet Cutting Application

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Steel fabrication of some structural components for earthquake resistant design requires controlled cross-sections with reduced areas and precise contoured transitions. Some examples include reduced beam sections in moment resisting frames and yielding core elements of buckling-restrained braces. To fabricate these sections, traditional techniques include machining or plasma and oxyfuel cutting. Plasma and oxyfuel cutting produces a heat effected zone (HAZ) in the region of the cut and if not removed by secondary processing may provide a mechanism for crack initiation. A more recent fabrication technique, not widely used for structural steel fabrication, is abrasive water jet cutting.

Water jet cutting was originally developed in the 1960s for composite materials and aerospace applications (Valenti, 2001). In a typical application, water is pressurized to 5,000 psi–60,000 psi (34.5 MPa–413.7 MPa) and focused through a jewel orifice (sapphire, diamond, etc.). To cut soft materials such as wood, plastic, rubber, and textiles the water jet alone is sufficient. Abrasive is added to the water cutting stream in a small diameter mixing tube for hard materials such as steel, hardened alloys, ceramics, glass, and rock. Steel up to 12 in. (304.80 mm) thick can be cut; however, most steel plate material currently cut with abrasive water jet techniques is 2 in. thick or less. Abrasives used in the process include crushed garnet, olivine sand, aluminum oxide, and corundum with 0.008 in. to 0.020 in. (0.203 mm to 0.508 mm) particle size. Crushed garnet is the most commonly used abrasive because of its relatively low cost and high cutting speed. Cost of the abrasive material accounts for two-thirds of the overall process cost (Valenti, 2001).

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Table 1. Comparison of Cutting Rates

Steel Material Thickness (in.) (1)	Cutting Rate		
	AWJ (in/min) (2)	Oxyfuel (in/min) (3)	Plasma (in/min) (4)
3/4	6.5	12	45
1-1/4	3.5	10	28

Abrasive water jet (AWJ) cutting produces an accurate, clean cut to finished or near finished quality. Cut quality is influenced by water jet pressure, water jet travel rate, abrasive flow rate, and abrasive grain size (Singh and Jain, 1995). Typical AWJ cutting machines consist of a high-pressure pump and abrasive delivery system that supplies the cutting stream to a computer numeric controlled (CNC) cutting head. A water tank/table beneath the cutting head supports work material, catches water and spent abrasive, and dampens noise from the cutting stream. Typical table sizes and cutting envelopes are 4 ft × 4 ft (1.22 m × 1.22 m), 4 ft × 8 ft (1.22 m × 2.44 m), and 6 ft × 12 ft (1.83 m × 3.66 m). Additional fixtures enable the cutting of longer pieces but require repositioning the work part-way through the cutting process. Part height is limited by cutting head clearance over the table. This height limitation is typically 10 in. for AWJ cutting machines in most fabrication shops. Large AWJ cutting machines, used in the aerospace industry, are available with cutting envelopes of 20 ft × 50 ft × 5 ft. Machines of this size could easily handle fabrication of reduced beam sections for A992 rolled W-shapes and other large earthquake resistant steel members.

Typical AWJ cutting rates along with oxyfuel and plasma cutting rates are given in Table 1 for steel material thicknesses used in the yielding core application discussed below. AWJ cutting requires greater cutting time compared with thermal cutting methods. Economy using AWJ cutting is achieved because grinding to remove slag or notches produced from thermal cutting is not required.

Little heat is generated in AWJ cutting and material is removed from a narrow kerf, typically 0.035 in. (0.889 mm), by high-pressure erosion (Kalina, 1999). The heat affected zone (HAZ), typical of oxyfuel or plasma cutting, is not produced and therefore any secondary processing to remove the HAZ is not required with AWJ cutting (Kalina, 1999; Singh and Jain, 1995).

Little information is available in the technical literature on AWJ cutting, and no detailed information is found related to structural steel fabrication using this technique.

YIELDING CORE APPLICATION

Full-scale testing of a new type of buckling-restrained brace was recently completed at Oregon State University (Newell, 2003). The device relies on hysteretic yielding of the steel material during cyclic deformations and requires large material ductility. To produce this ductile yielding, a reduced section was fabricated and placed within a steel tube for confinement. The A36 steel yielding cores, shown in Figure 1, were cut using AWJ techniques. Water jet pressure was 50,000 psi (344.7 MPa) with a 0.040 in. (1.016 mm) diameter mixing tube and a 0.016 in. (0.406 mm) diameter orifice. Crushed garnet of 0.0098 in. (0.249 mm) particle size was used as the abrasive. Cutting speed was approximately 3.0 in/min (76.2 mm/min). Table dimensions were 72 in. by 144 in. (1.83 m by 3.66 m) but the yielding core cut length was 158 in. (4.01 m) Additional fixtures were required and steel yielding cores were repositioned half way through the cutting process to accommodate a cut length longer than the table length. The transition between the two cuts was smoothed using a die grinder and an abrasive sanding disc.

MECHANICAL TESTING

As no information is currently available for AWJ cut structural steel components, a limited number of tensile tests were performed to assess potential differences between conventionally machined and AWJ cut coupons. Four tension coupons were tested in accordance with ASTM Standard E8. Two pairs of general machining and water jet coupons were taken from portions of two different 20 ft (6.10 m) lengths of 1¼ in. × 6 in. (31.75 mm × 152.40 mm) A36 bar stock. The steel was from the same heat and coupons were taken from the center of the 6 in. (152.40 mm) width as shown in Figure 2. General machining coupons (GM 1,2) were machined to width and reduced cross-section using standard milling machine techniques. AWJ coupons (AWJ 1,2) were water jet cut to width using the same process as the yielding cores described previously. The reduced cross-section of the AWJ coupons was milled.

Load and extension data on the 2 in. gage length were recorded at a continuous rate of 5 Hz during testing and post-processed. Stress-strain curves for both sets of specimens are shown in Figure 3 and Figure 4 and summarized in Table 2. Ultimate stress values for GM and AWJ coupons were nearly equivalent. Yield stress values for AWJ coupons were slightly less than the corresponding GM

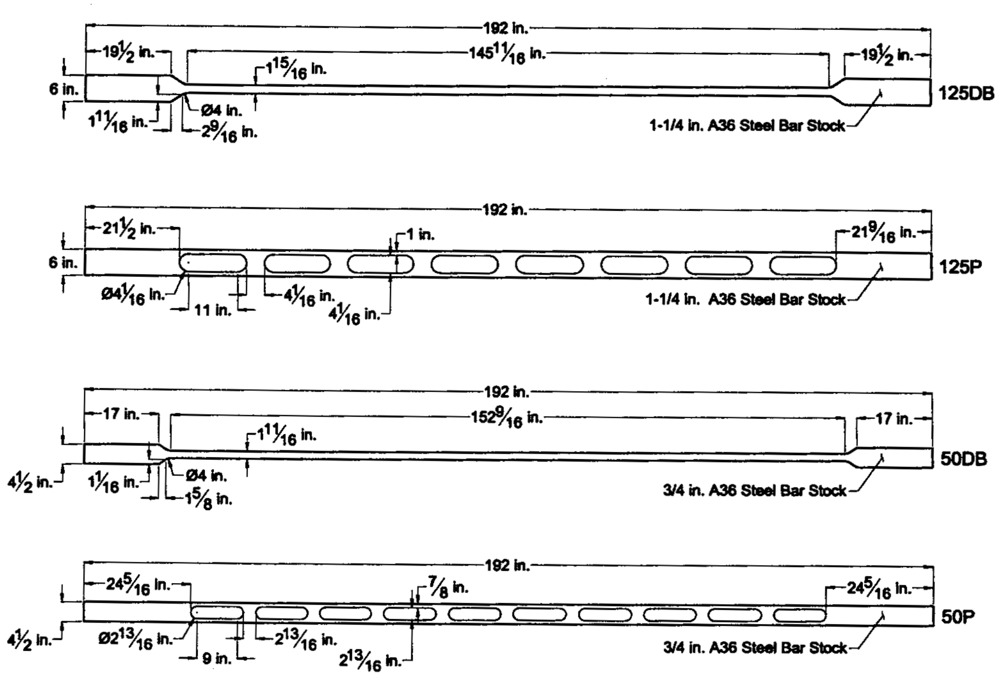

Fig. 1. Yielding core geometries.

Table 2. Tension Coupon Results

	F_y		F_u		
	(ksi)	(MPa)	(ksi)	(MPa)	(%)
(1)	(2)		(3)		(4)
GM 1	50.3	346.8	70.8	488.1	28
WJ 1	48.9	337.1	69.6	479.9	26
GM 2	50.8	350.2	71.4	492.3	31
WJ 2	47.8	329.6	71.5	493.0	29

coupons. Elongation values after fracture for AWJ coupons were 2 percent less than the GM coupons. Further testing would increase the knowledge base and quantify any differences in mechanical behavior of A36 steel from AWJ cutting.

CONCLUSIONS

Abrasive water jet cutting may provide an economical fabrication technique for earthquake resistant structural steel components. A limited number of tensile tests were performed on traditionally machined and AWJ cut A36 steel tension coupons. Results indicate only slight differences in

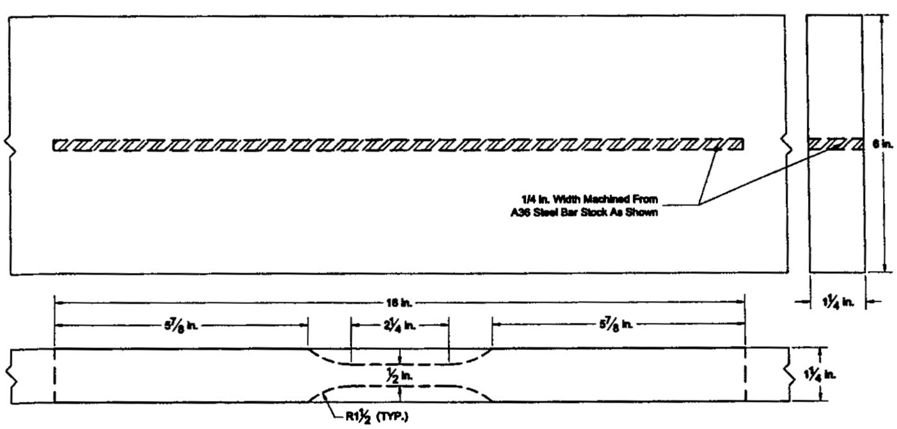

Fig. 2. Tension coupon geometry.

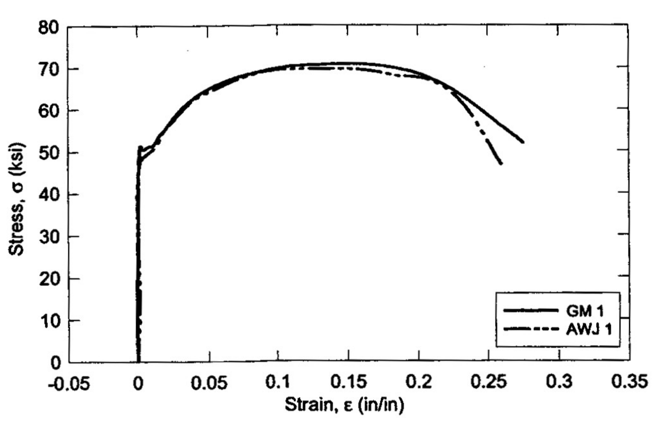

Fig. 3. Stress-strain curve for tension coupon GM-1 and AWJ-1.

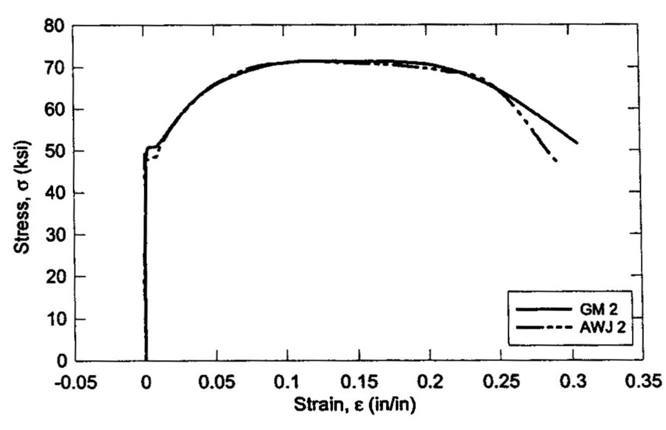

Fig. 4. Stress-strain curve for tension coupon GM-2 and AWJ-2.

the stress-strain behavior of coupons fabricated with the two different methods. Further testing would provide additional information on the mechanical behavior of AWJ cut structural steel and facilitate additional use of this fabrication technique.

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