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The Influence of Weld Strength Mismatch on the Fitness–for–Service of High Strength Steel Structures

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In welded construction, the solidified metal and surrounding region (heat affected zone, or HAZ) have fracture toughness that is characteristically lower and less well controlled than that of the base material joined due to inferior metallurgical quality of the metal in the weld region [Kerr, 1976]. Further, welding produces defects which must be considered to insure structural integrity against fracture. Taken together, the low fracture toughness and high defect probability characteristic of weldments provide incentive to prevent large deformations in welded regions. For this reason, many codes require use of weld metals whose strength exceeds that of the plates joined [ASME, 1980; AWS, 1980; USDOT, 1979]; a practice referred to as *overmatching*. Overmatched welds generally force plastic deformation into the lower strength plate [Denys, 1990] where better fracture resistance and fewer defects are expected.

Unfortunately, overmatching weld metal strength has economic and technical disadvantages which undermatched (weld metal yield strength less than plate yield strength) construction might alleviate. For example, welding of high strength steels requires preheat to prevent hydrogen cracking. Satoh and co–workers [1978] demonstrated that preheat requirements could be halved by switching to undermatched construction. This change produced a significant energy savings and increased productivity because the lower preheat temperature permitted extension of the welder's duty cycle. Howden, et al. [1983] found that, for welding the HY steels commonly used in Naval construction (80 to 130 ksi nominal yield strength), the use of undermatched welds increases weld metal deposition rate relative to overmatched practice. Undermatching also reduces the need to hold electrodes at an elevated temperature prior to use, reduces the lack of fusion / lack of penetration defect rate (higher heat inputs improve arc penetration), reduces restraint stresses, and increases weld metal toughness.

The forgoing information suggests that overmatched welds, while used effectively in low strength steel construction, may not be as advantageous for structures fabricated from higher strength grades. However, relative to overmatching, undermatching significantly increases the strain carried by the weld, and thereby the applied driving force for fracture in the weld region. Therefore, current practice generally prohibits undermatching. Limited experimental data indicates that undermatched welds may have slightly higher toughness than overmatched welds to resist the increased driving force for fracture [Cunha and Pope, 1986]. However, experimental and finite element investigations demonstrate that weld strength mismatch affects significantly the relationship between remotely applied loading and crack–tip driving force [Read and Petrovski, 1990; Cray, et al., 1989]. Consequently, studies on the effects of strength matching on fracture toughness are regarded as inconclusive because the formulas used to calculate fracture toughness values from experimentally measured quantities neglect the presence of a weld in the testpiece [ASTM E813, 1989; ASTM E1290, 1989]. Commonly used techniques for assessing structural defects [PD6493, 1991; Milne, et al., 1986] also neglect the effect of weld strength mismatch. Therefore, these techniques cannot quantify the effect of weld strength mismatch on structural defect tolerance. Before undermatching is accepted as an alternative to conventional overmatched practice, techniques that address weld strength mismatch are needed to measure fracture toughness and to assess structural defects.

Acceptance of undermatched weld metal systems as a more economical alternative to conventional overmatched welds for high strength steel construction is impeded by an inability to relate applied loading to crack driving force (i.e. J or CTOD) for both fracture test specimens and structures containing welds. Previous studies have quantified the effects of weld strength mismatch on the formulas used to relate measurable quantities to J and CTOD in fracture toughness tests [Kirk and Dodds, 1992; Leggatt and Gordon, 1992]. In this investigation, two–dimensional, plane–strain finite element analyses of M(T) specimens containing welds are described for a wide range of strain hardening coefficients, weld sizes, and strength mismatch levels to quantify the influence of weld strength mismatch on fitness–for–service assessment procedures. Table 1 describes the configurations considered. This study focuses on cracks that are small compared to the panel width as these represent most closely the conditions encountered in structures. All cracks are located on the weld centerline parallel to the weld axis. Loading is applied transverse to the weld axis, which generates nominally equal stresses in both weld and plate material. Weld strength mismatch exerts a greater influence for this configuration than for equal–strain loading (weld axis parallel to the loading axis). Moreover, welds stressed transverse to their axis are common in critical members of many engineering structures.

Table 1: M(T) specimens modelled.

a/W	Weld Metal Strain Hardening Coefficient (n)	Percent Mismatch		
		20% Under	20% Over	75% Over
0.025	13	0.5 to 15	0.5 to 15	0.5 to 15
	6	0.5 to 10	0.5 to 10	0.5 to 10
0.050	13	0.5 to 10	0.5 to 10	0.5 to 10
	6	0.5 to 10	0.5 to 10	0.5 to 10

Notes:
1. Table entries indicate range of weld height to crack length (h/a) values analyzed.
2. Constitutive properties used in these models are detailed below.
3. Throughout this chapter, analyses having a weld metal strain hardening coefficient of 13 are referred to as "low" strain hardening whereas analyses having a weld metal strain hardening coefficient of 6 are referred to as "high" strain hardening.

Percent Mismatch	Weld Metal		Plate	
	n	σ_y [ksi]	n	σ_y [ksi]
20% Under	13	104	18	130
20% Over			10	86
75% Over			6	60
20% Under	6	60	9	75
20% Over			5	50
75% Over			4	34.5

REFERENCES

ASTM E813–89, "Standard Test Method for J_{Ic}, A Measure of Fracture Toughness," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1989.

ASTM E1290–89, "Standard Test Method for Crack–Tip Opening Displacement (CTOD) Fracture Toughness Measurement," American Society for Testing and Materials, Philadelphia, Pennsylvania, 1989.

American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1980.

American Welding Society, D1.1–80, Structural Welding Code, 1980.

Cray, M.J., Luxmoore, A.R., and Sumpter, J.D.G., "The Effect of Weld Metal Mismatch on J and CTOD," in *Proceedings of the European Symposium on Elastic–Plastic Fracture Mechanics* (to be published), Freiburg, F.R.G., 1989.

Denys, R. M., "Wide–Plate Testing of Weldments: Part III – Heat–Affected Zone Wide–Plate Studies," *Fatigue and Fracture Testing of Weldments, ASTM STP 1058*, H.I. McHenry and J.M. Potter, Eds., American Society for Testing and Materials, Philadelphia, Pennsylvania, pp. 204–228, 1990.

Kerr, W.H., "A Review of Factors Affecting Toughness in Welded Steels," *International Journal of Pressure Vessels and Piping*, Vol. 4, pp. 119–141, 1976.

Kirk, M.T., and Dodds, R.H. Jr., "Experimental *J* Estimation Formulas for Single Edge Notch Bend Specimens Containing Mismatched Welds," *Proceedings of the Eleventh International Conference on Offshore Mechanics and Arctic Engineering*, American Society of Mechanical Engineers, Vol. III, Part B, pp. 439–448, 1992.

Leggatt, R.H., and Gordon, J.R., "3D Elastic–Plastic Finite Element Analysis of Shallow Cracks in Single Edge Notch Bend Specimens," *Proceedings of the International Conference on Shallow Crack Fracture Mechanics Toughness Tests and Applications*, September 1992, Cambridge, U.K.

Milne, I, et al., "Assessment of the Integrity of Structures Containing Defects," CEGB Report R/H/R6–Rev. 3, 1986.

Read, D.T., and Petrovski, B.I., "Elastic–Plastic Fracture at Surface Flaws in HSLA Weldments," *Proceedings of the Ninth International Conference on Offshore Mechanics and Arctic Engineering, Volume III*, American Soicity of Mechanical Engineers, New York, New York, pp. 461–471, 1990.

PD 6493:1991, "Guidance on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures," British Standards Institution.

Satoh, K. et al., "Prevention of Weld Crack in HT80 Heavy Plates with Undermatching Electrodes in Application to Fabricating Penstock," *Transactions of the Japan Welding Society*, Vol. 9, No. 1, pp. 17–21, April 1978.

U.S. Department of Transportation, Code of Federal Regulations, Title 49, Parts 191 and 192, "Regulations for the Transportation of Natural Gas and Other Gases by Pipeline, 1979.