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Dynamic Fracture Toughness of Armour Grade Quenched and Tempered Steel Joints Fabricated Using Low Hydrogen Ferritic Fillers

G Magudeeswaran[1], V Balasubramanian[2], S Sathyanarayanan[3], G Madhusudhan Reddy[4], A Moitra[3], S Venugopal[3], G Sasikala[3]

[1. Department of Mechanical Engineering, Pannaikkadu Veerammal Paramasivam College of Engineering and Technology for Women, Dindigul 624708, Tamil Nadu, India; 2. Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar 608 002, Tamil Nadu, India; 3. Materials Mechanics Section, Indira Gandhi Center for Atomic Research, Kalpakkam 603 102, Tamil Nadu, India; 4. Metal Joining Section, Defence Metallurgical Research Laboratory, Hyderabad 560 058, Andhra Pradesh, India]

Abstract: The armour grade quenched and tempered steel joints fabricated using low hydrogen ferritic steel (LHF) filler exhibited superior joint efficiency owing to preferential ferrite microstructure in the welds and also they offered required resistance to HIC. However, the combat vehicles used in military operations will be required to operate under a wide range of road conditions ranging from first class to cross country. Structural components in combat vehicles are subjected to dynamic loading with high strain rates during operation. Stress loadings within the vehicle hull of these vehicles are expected to fluctuate considerably and structural cracking especially in welds during the service life of these vehicles can lead to catastrophic failures. Under these conditions, fracture behaviour of high strain rate sensitive structural steels can be better understood by dynamic fracture toughness (K_{1d}). Hence, an attempt was made to study dynamic fracture toughness of the armour grade quenched and tempered steel and their welds fabricated using LHF consumables. The experimental results indicate that the K_{1d} values of the joints fabricated by shielded metal arc welding (SMAW) are higher than those of the joints fabricated using flux cored arc welding (FCAW) process.

Key words: quenched steel; tempered steel; low hydrogen ferritic steel; dynamic fracture toughness

The important criterion for components used in combat vehicle construction is that it should satisfy the ballistic requirements. Ballistic testing, technically speaking, is just a typical high velocity test of impact behaviour of the material, which determines the initial high capacity of energy absorption before cracking and resistance to penetration of a projectile. The armour components going into service cannot always be subjected to ballistic proving as it is a destructive type of testing and cannot be performed frequently for all the components. Ballistic properties mainly depend upon the toughness (combination of strength and ductility) and hardness of the material. Once the values of impact strength, tensile strength, and hardness of the proved proof welds are known, it can be expected that the armour steel joints will satisfy, within limits, the ballistic standards[1]. However, the combat vehicles used in military operations will be required to operate under a wide range of road conditions ranging from first class to cross country. Structural components in combat vehicles are subjected to dynamic loading with high strain rates during operation. Stress loadings within the vehicle hull of these vehicles are expected to fluctuate considerably and structural cracking especially in welds during the service life of these vehicles can lead to catastrophic failures[2]. Under these conditions, fracture behaviour of high strain rate sensitive structural steels can be better understood by dynamic fracture toughness. Thus, knowledge on the dynamic fracture toughness of materials is a prerequisite for their reliable use as structural materials[3] especially in combat vehicle construction and is very much applicable for welded

Biography: G Magudeeswaran(1975—), Male, Doctor Candidate, Professor; **E-mail**: magudeeswaran@yahoo.com;
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joints also.

The welding consumables made of austenitic stainless steel (ASS) are being used for welding quenched and tempered steels, as they have higher solubility for hydrogen in austenitic phase, to avoid hydrogen induced cracking (HIC). Even with austenitic stainless steel consumables under high dilution, the risk of HIC prevailed. Further, duplex microstructure (austenite and delta ferrite) in the weld region of the armour grade quenched and tempered steel joints fabricated using ASS fillers drastically reduces the joint efficiency (ratio of ultimate tensile strength of the joint and the base metal) and is also very expensive. In recent years, the developments of low hydrogen ferritic steel (LHF) consumables that contain no hygroscopic compounds are utilized for welding of quenched and tempered steels. The armour grade quenched and tempered steel joints fabricated using LHF filler exhibited superior joint efficiency owing to preferential ferrite microstructure in the welds and also they offered required resistance to HIC. Fusion welded structures have both strength and microstructural heterogeneity owing to various parameters such as heat input, consumables, and process selection[4-6]. The microstructural heterogeneity will have a drastic influence in the dynamic fracture toughness of the armour grade quenched and tempered steel welds. Hence, an investigation was carried out to evaluate the dynamic fracture toughness of armour grade quenched and tempered steels fabricated by SMAW (manual) and FCAW (semi-automatic) processes using LHF welding consumables.

1 Experimental

The base metal used in this investigation is a quenched and tempered steel, closely confirming to AISI 4340 specification. Rolled plates of base metal with thickness of 14 mm were sliced into the required dimensions (300 mm × 100 mm) by abrasive cutters and grinding. Single 'V' butt joint configuration was prepared to fabricate the joints by SMAW and FCAW processes by using LHF consumables. The joint fabricated using LHF consumable and SMAW process is referred as SF joint and the joint fabricated using LHF consumable and FCAW process is referred as FF joint. The chemical composition of the base metal and weld metals are presented in Table 1. The process parameters used to fabricate the joints are given in Table 2. The transverse tensile strength of the base metal and the joints evaluated from an earlier investigation[5] is presented in Table 3.

Standard Charpy V-notch specimens (10 mm × 10 mm × 55 mm) were extracted in T-L direction at the mid-thickness area of the base metal and the weld metal. In the welded specimen, the V notch was located at the center of the weld metal. The specimens were fatigue pre-cracked with a constant stress ratio (R=0.1) as per ASTME 1820-06 standard. The initial crack lengths determined by post-test optical measurements as per the nine point averaging method were in the range of $0.46W-0.55W$ (where W is the specimen width, mm); these may be compared with the range of $0.45W - 0.7W$ prescribed by this standard. Pre-cracked Charpy specimens were impact-tested at room temperature (23 ℃) using an impact machine of 358 J in capacity provided with an instrumentation system. The analogue output was captured by a 12-bit transient recorder (with a maximum speed of 10 MHz) interfaced with a personal computer. The loading rate at the point of impact has been approximately 5.12 m/s. Load *vs* time (*P-t*) data obtained from the tests were stored as ASCII file

Table 1 Chemical composition in mass percent of base metal and filler metal %

Type of material	Notation	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
Base metal (closely confirming to AISI 4340 grade)	BM	0.315	0.239	0.53	0.018	0.009	1.29	0.451	1.54	Balance
LHF steel (AWS E11018-M)	SF	0.050	0.242	1.30	0.020	0.014	0.133	0.222	2.12	Balance
LHF steel (AWS E110T5-K4)	FF	0.042	0.280	1.23	0.009	0.009	0.54	0.51	2.21	Balance

Table 2 Welding conditions

Parameters	SF	FF
Preheating temperature/℃	100	100
Interpass temperature/℃	150	150
Electrode baking temperature/℃	300	—
CO_2 gas flowrate/(L · min^{-1})	—	12
Filler diameter/mm	4	1.6
Current/A	160	220
Voltage/V	23	30
Heat input/(kJ · mm^{-1})	1.33	2.03