Optimization of Welding Procedure and Its Impact on Properties of Elastomeric Diaphragm for Positive Expulsion Device

Danish Noman, Irfan Mahmood Khan, Muhammad Zeeshan Siddiqui, Majid Shahzad, Bilal Ahmed

***Abstract*— Positive expulsion devices are widely used in secondary propulsion systems to assist the incessant flow of fuel against sloshing during flight [1]. Welding of positive expulsion tank is intricate due to presence of elastomer along with retainer ring and vessel. Direct exposure to high temperature field may cause deterioration in mechanical properties (Compression set, Hardness and Tensile strength etc.) of elastomer. Purpose of the research is to investigate the optimal conditions to minimize the direct temperature exposure of elastomer (FKM) mounted in a prototype. Temperature in the experimental setup is monitored using thermocouples to determine the safe margin for elastomer with respect to weld pool by varying welding parameters. Mechanical properties of the FKM elastomer didn't unveil any significant degradation after thermal exposure of elastomer during Tungsten Inert Gas (TIG) welding of stainless steel 304 without incorporating a heat sink.**

Index Terms— Positive expulsion devices, Heat Effected Zone, secondary propulsion system, Elastomeric diaphragm, Thermal integrity, FKM

I. Introduction

Diaphragm is one of the most conventional expulsion mechanisms used in the majority of the secondary propulsion systems in early stages. Diaphragm tanks are positive expulsion devices which have a membrane to separate the propellant from the pressurant compartment. Metallic shell, elastomeric diaphragm and a holding retainer ring inside the shell are main constitute of expulsion tank.

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Welding of retainer ring with metallic shell is a critical concern because of the presence of FKM (viton) based elastomeric diaphragm or membrane. Basic configuration of the assembly is shown in Fig. 1. Temperature field generated by welding operation at desired position can cause degradation in mechanical properties of viton elastomer. In range 340-400 ^{o}C, there is a considerable breakdown of the elastomer macromolecules with separation of three fractions as well as polymeric residue [2]. In this research work, certain experiments are performed to estimate the critical temperature range for elastomer. Furthermore, the impact of thermal exposure on properties of FKM based elastomer is also studied.

Thermal degradation in terms of mechanical properties of elastomer is determined at different temperature fields generated by welding. It was experimentally evaluated that the available FKM elastomer cannot withstand the thermal exposure of 500^{o}C even for a few seconds. With existing setup this temperature may be obtained adjacent to partially melted zone of weld. So, the welding parameters and position of elastomeric bead is to be chosen accordingly to minimize the thermal degradation of elasomer.

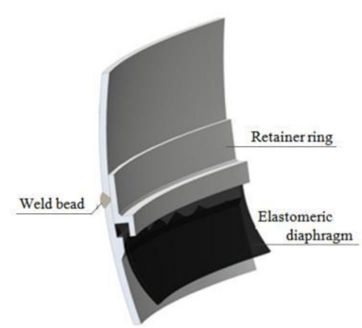

Fig. 1 : Basic schematic of elastomeric diaphragm

Tungsten Inert Gas (TIG) is used to conduct the study because of its feasibility to be used in actual application. The TIG welding process is so good that it is widely used in the high-tech industry applications such as, nuclear industry, aircraft, food industry, maintenance and repair work and some manufacturing areas [3]. The effect of welding current and welding speed on weld quality and temperature field of test specimen are also studied in this experimental study. Stainless Steel 304 is used as a base metal with FKM as an elastomeric diaphragm material. Increment in current of welding can cause low quality weld but decrement in current may lead to sticking of the filler wire. Welding speed is an important parameter because if the welding speed is increased, power or heat input per unit length of weld is decreased, therefore less weld penetration results [4]. Welding bead is primarily controlled by the welding speed.

Since temperature field by welding process also depend on welding parameters, it is necessary to study the welding optimization in terms of parameters to minimize the thermal degradation of elastomeric diaphragm during welding. Welding current and welding speed are varied during experiments while keeping the other parameters fixed.

As mentioned earlier temperature higher than 500 o C may cause problem even in less than a minute. FKM based elastomer is characterized by Tensile Strength, % elongation, % Compression Set and Hardness. Mechanical properties of the elastomer at 300oC, 340oC and 390oC are compared to simulate the actual and worst case scenario of the process

II. Materials and Experimental Procedure

A. Materials

Stainless Steel (SS-304) sheets (150 x 100 x 3mm) were used for welding experiments. Cooling was done by natural air after welding at room temperature. Nine samples were used for all possible pairs of changing welding current and speed. Percent compositions of base metal and filler rod are shown in Table I. Viton *Type A* elastomer is used to conduct the study considering its compatibility with the fuel to be used inside the expulsion device in actual application.

TABLE I
Base metal and Filler material composition

Elements	Base metal (SS304)	Welding Filler (SS308L)
Cr	17.5~19.5	19.5~22
Ni	8~10.5	9~11
Si	0.75	0.65
C	0.07	≥0.03
P	0.045	0.03
S	0.03	0.03

B. Experimental setup

TIG welding machine having current range 0-600 A and voltage up to 50 V is used. Welding torch is fixed using a clamp at approximate 90° angle to attain a stable and continuous arc. Movable tractor unit allow the uniform movement at specified speed. Distance between the torch tip, work piece and angle of torch tip can also be control using the adjustable knob. A metallic frame is used to hold the work piece to avoid any distortion. The welding setup is shown in Fig. 2. Ar gas is supplied to the welding torch with a particular flow rate. All fixed parameters used to conduct this study are shown in Table II. Tungsten electrode is connected to the negative terminal of power supply. This type of connection is the most commonly called as DCSP (Direct current straight polarity). With the tungsten being connected to the negative terminal it will only receive 30% of the welding energy (heat) [4]

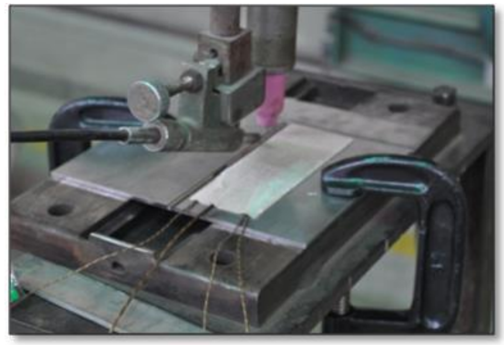

Fig. 2: TIG Welding Setup

TABLE II
TIG welding parameters used for this study

Parameter	Range
Welding current (A)	80~100
Voltage (V)	12.5
Speed (mm/s)	1.1 ~ 1.6
torch distance (mm)	3
Gas flow rate (cfh)	20
Current type	DCSP
Welding Rod	SS-308
Wire feed (mm/s)	1.5

Combination pairs of welding speed and current are made to get the better weld quality with suitable temperature field. Pairs of test parameters are shown in Table III.

Table III
Set of Experiments

S. No.	Welding speed (mm/s)	Current (Amp)
S1	1.1	80
S2	1.1	90
S3	1.1	100
S4	1.6	80
S5	1.6	90
S6	1.6	100
S7	1.3	80
S8	1.3	90
S9	1.3	100

Elastomeric diaphragm's seating is about 30 mm from weld pool as imitated by its actual position inside tank. K-Type Thermocouples were placed accordingly on test specimen to acquire temperature field with respect to adjustments in welding parameters.

As described earlier temperature between 340~400°C may impart shrinkage, cross linking, hardening, and change in other mechanical properties of elastomers. Electric furnace is used to condition the elastomer samples at different temperature for specific periods of time. All the samples were conditioned at 300 ^{O}C, 340 ^{O}C and 490 ^{O}C for the duration of 3 minutes each. Thermocouple data give the commonsensical assumption about the time period for cooling in case of natural air cooled. Assuming the scenario; 3 minutes' time is decided for thermal conditioning.

FKM samples for TS, are die cut samples and test are conducted according to ASTM D412 [5], at rate of 500 mm/min. Samples for % Compression set of elastomer are also die cut and ASTM D395[6] is followed to conduct the test. Similarly, the hardness test is carried out using ASTM D2240 [7].

III. Results and discussion

After completion of the welding process the welded specimen was kept properly on a table and the weld bead dimensions were measured with the help of a measuring instrument as describe in Fig. 3. Weld bead defines the weld quality and it highly depends on parameters like weld speed, current & voltages. There may be an uneven bead shape that may cause tribulations. High welding speed reduces wetting action and can cause porosity in weld bead along with uneven bead shapes.

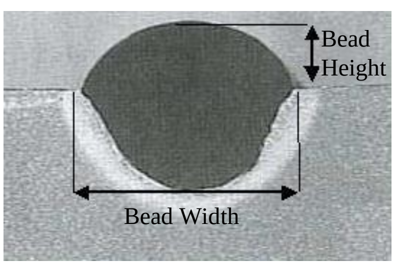

Fig. 3 : Weld Bead measurements

Weld reinforcement form factor (WRFF) for each pair is calculated. WRFF represent the Smoothness of the weld. Beads dimensions are given in Table IV. Cracks and porosity in weld was also analyzed to qualify the parameters. Considering the Cracks, porosity & WRFF; sample ID 2, 3, 6 and 9 may be suitable options for the welding operation but selection of parameters will be the tradeoff between weld quality and temperature obtained at desired position.

Table IV
Weld bead inspection

Sample #	Bead width	Bead height	WRFF
1	6.87	1.93	3.55
2	7.63	1.6	4.7
3	7.93	1.27	6.2
4	4.93	2.27	2.1
5	6.07	2.13	2.8
6	8.03	1.3	6.1
7	4.93	2	2.5
8	*6.63*	*0.33*	-
9	7.8	-	-

Peak temperature data on all concerned samples are shown in Fig 4. After data review, this may be stated that for all suitable sample pairs, maximum peak temperature must be lower than 300 ^{O}C at desired position from the weld line even at any instant during welding process. During welding of diaphragm tank, diaphragm seating beads may face the same temperature. Elastomer samples are tested after thermal conditioning that correspond the worst case during welding. Samples at unconditioned form are also tested to compare the change in properties.

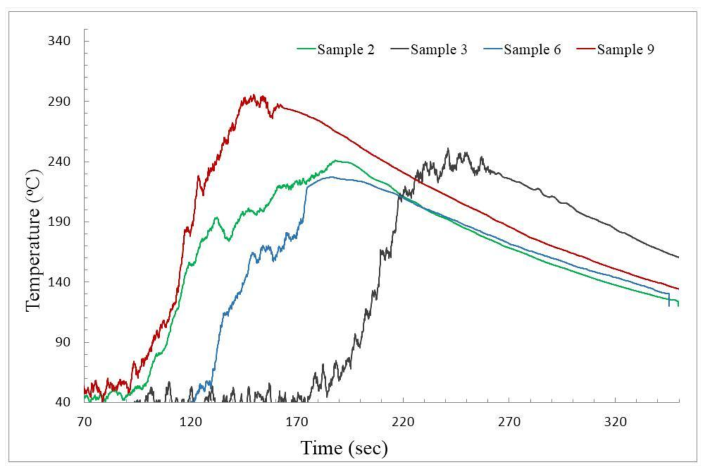

Fig. 4 : Temperature distribution for selected samples

After testing all samples, it was observed that there were no significant changes in elastomer properties at this temperature. It was decided to conduct similar tests at higher temperatures to observe the temperature range at which properties may deteriorate significantly. Results are shown in Table V.

TABLE V
ELASTOMER FKM PROPERTIES COMPARISON CONDITIONED AT DIFFERENT TEMPERATURE

PROPERTY	UN-CONDITIONED	300 o C	340 o C	390 o C
TENSILE STRENGTH (MPA)	5.5~5.6	5.6	5.5	2.1
COMPRESSION SET (%)	10.5	10.5	19.0	37.2
% ELONGATION	93	118	370	320
HARDNESS (SHORE A)	65.4	65	59.5	54.2

Comparison of properties clearly depicts increment in temperature results in decrement of TS. Similarly, there is a direct relation in percent elongation with the stated temperature but at 390 ^{o}C or after 340 ^{o}C it decreases, this could be due to disintegration of macromolecular elastomer chain consequently resulting in behavior changes. Compression set is one of the most important properties because elastomer has to be used as a membrane and increase in % compression set may causes leakage within the device. It increases as the stated temperature is raised especially between 340 ~ 390 ^{o}C.

IV. CONCLUSION

Some experimental setups are made to predict the mechanical behavior changes in FKM based elastomer at specific temperature field's due to welding process of diaphragm type tank. Following are some conclusions that can be made from this study,

TIG welding parameter can be utilized to obtain acceptable range of temperature, but along with this temperature field, weld bead quality must also be considered.

The position of elastomer in actual application i.e. 30mm from the weld pool is found to be suitable enough for performing welding operation because available FKM based elastomer is robust enough to sustain its properties at sudden rise of welding temperature for SS304 without installation of heat sink. Heat sink may be used to depress the thermal conduction.

Mechanical properties of available FKM based elasmoter deteriorate between 340oC ~ 390oC

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