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Stress Corrosion Cracking Analysis of The ER70S Wire and SS400 Stell Plate Joints

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Abstract

The susceptibility of weld joints to the stress corrosion cracking (SCC) load alarmed the researchers since pipeline blow-out which were initiated in the area closed to the weld joints. This article is evaluating the SCC resiliences of the ER70S wire filler metal to the SS400 plate. The capacitive discharge welding (CDW) with varied angle of the filler metal as an independent variable is applied, whilst the other parameters were kept constant. The joint, then exposed to the SCC load, *i.e.*, dipped in the 1M HCl solution with varied external tensile load to obtain the dependent variable: time to failure (time to brake). The results show that, generally, a sharper wire tip provides higher SCC resilience accept what was shown by the 30° speciment. With the sharper wire tip, the higher volume of weld nugget is provided which guarentee the enough number of weld metal. However, the impact phenomenon in the CDW process splashed this too much nugget beyond the formed joint which is proven by many spatter in the weld joint. This thrown out nugget substance in turn decreases the intended nugget volume to form the joint. The results show the 60° wire tip angle provide the joint with the highest SCC resiliences, indicated by the longest time to brake when loaded with an equal external load.

1. Introduction

The failure of a construction or machine element traditionally is evaluated via the induced stresses which is called catastrophic failure [1, 2]. There is also a failure which is time dependent such as a shaft with a fatigue load or a material exposed in corrosive environment [3]. The failure which combines both phenomena added with the crack existence which may initiated by voids and imperfection in microstructure known as stress corrosion cracking (SCC) [4-6]. The awareness to include SCC in the welding joints is initiated by the blow up of pipeline in Argentina [7], pipeline transporting natural gas from central Australia to Sydney and Trans Canada pipeline exploding in Winnipeg [8].

The stress can be both residual stress and the stress due to external load. In the welding process, the residual is always embedded due to local heating and cooling of the welding processes [9]. In many cases the thermal stresses cause the thermal strain which exceeds the yield stress. When the structure is cooled down to room temperature there is a misfit due to the plastic strain and in turn produces residual stress. Voids and the microstructure imperfectness with the external load cause stress concentration that initiate cracks which will grow in line with the stress. It can be said, naturally two ingredients of SCC already existed in the welding joints, once it exposed to corrosive environment the requirement for SCC has been provided and the joints will fail due to SCC phenomenon [10].

The ER20S filler metal is widely applied in the welding process due to its mechanical properties and weldability [11-13]. CDW is widely applied in North America's automotive industries and predicted will be accelerated because of the need to apply dissimilar welding for the lightweight mobiles [14 – 15]. This article discusses the SCC resilience of the ER70S and SS400 plate joints. The results give basic knowledge for the next research of the SCC resilience especially for SS400 welding joints using ER70S filler metal.

2. Experimental Set Up

This research used an experiment method with independent variable is the tip angle of ER70S wires and the dead load which was converted as tensile stress. Other parameters such as corrosive environment is set as a constant parameter. Making the welding joint of ER70S wire on to SS400 steel plates is the first step. All the welding parameters are constant except for the wire tip which is varied. The CDW energy for welding is set to 100 Joule. Figure 1 shows the CDW process schematically with a jig and fixture which is especially intended for this research.

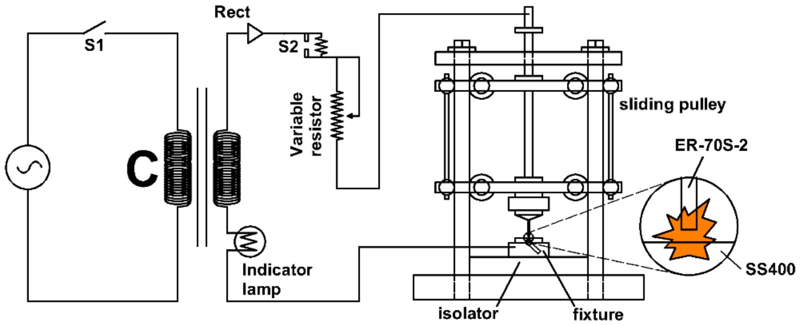

Fig. 1 *The CDW process*

The ER70S-SS400 joints then are set in the SCC apparatus, exposed to the 1M HCl and loaded with varied external load to obtain the time to fail which is the main dependent variable results of this research. Other data such as tensile strength of the joints, macro photos of the fracture surfaces and SEM-EDS are used to get reasons of the obtained relation between tensile stress and time to fail for the CDW joints with varied ER70S wire tip. Figure 2 shows the jig and fixture which is particularly designed to carried out the SCC test for this research. The chemical composition and mechanical properties of ER70S and SS400 are shown in Tables 1 and 2 respectively. Figure 3 is a photo of ER70S wire and the SS400 plate and Table 3 tabulates CDW welding parameters which are constant.

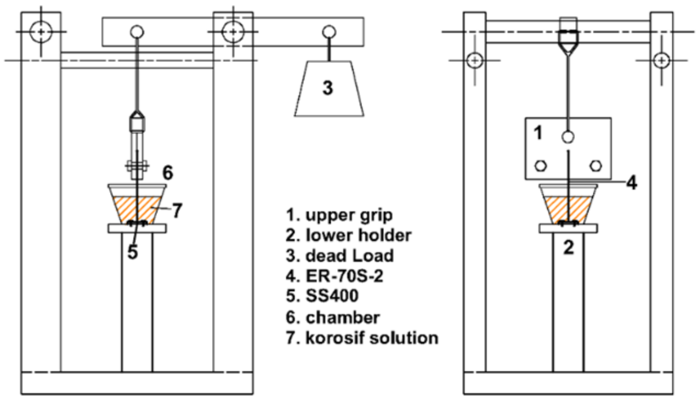

Fig. 2 *Jig and fixture for SCC test*

Table 1 *Chemical composition and mechanical properties of ER70S-2 wires*

Material	Fe	C	Si	Mn	Cu	Ni	Cr	Mo
Carbon Steel	97,7	0,07	0.040	0.90	0,5	-	-	-

AWS classification	Tensile Strength		Yield Strength		Elongation
A5.18	psi	MPa	psi	MPa	%
ER70S-2	70.000	480	58.000	400	22

Table 2 *Chemical composition and mechanical properties of SS400 plates*

Symbol	C	Mn	P	S
SS400	0,30 max	-	0,050 max	0,050 max

Symbol	Tensile Strength (N/mm²)	Yield Strength (N/mm²)	Elongation (%)
SS400	400 to 500	245 min	21 min

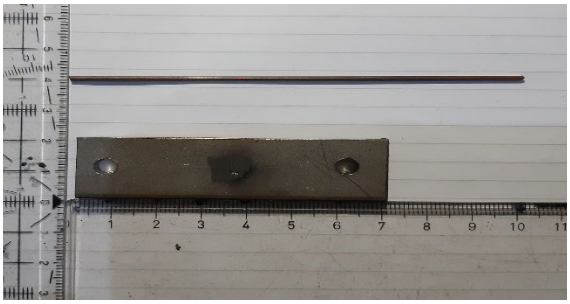

Fig. 3 *ER70S wire and SS400 plate*

Table 3 *Parameters of hotspot CDW*

Parameter	**Value**
Energy	100 J
ER70S tip angle	30°, 60°, 90°, 120°, 150°
Pressure	40 N
Drop Height	4mm
Voltage	75 VD

The research was performed at Manufacturing Process Laboratory of Mechanical Engineering Department, Brawijaya University, Malang – Indonesia. The SEM for BSE and EDS modes carried out at Central Laboratory of Biology Sciences, Brawijaya University, Malang – Indonesia.

3. Results and Discussion

The CDW processes is applied at a jig and fixture as shown in Figure 1. The "drop" distance of the wire was set to 4mm and the jig weight which determines the impact pressure is 8.7 kg. The simplest and easiest way to evaluate the quality of the CDW joints is by evaluating their tensile strength. The tensile strength was applied using a jig and fixture shown in Figure 2 without applying the corrosive liquid. The dead load increased gradually until the joint is broken and the load converted to the stress at the specimens. Using this method, the tensile strength of the joint for varied parameters can be obtained as it is presented in Table 4 and Figure 4. In Figure 4 the left ordinate is represented in "ultimate load" which was directly obtained from the test, whilst in the right ordinate is in „ultimate strength" in the stress unit (MPa) obtained from calculation. Using the same tool (Figure 2), it is obtained the tensile strength of the ER70S wire (482.54 MPa).

The main result of this research is data obtained from SCC test which is depicted in Figure 2. The abscissa is the percentage of ultimate strength which is practically easier just setting the external load to certain percent of its "ultimate load". The data gathered from the SCC test is the time to fail from specimens with varied tip angle of filler metal. For certain tip angle it was provided 3 specimens and 5 variations of the wire tip angel of ER70S: 30°, 60°, 90°, 120°, 150°. Using the data, the effect of the wire tip angle to the SCC resiliencies in term of the time to fail. The corrosive environment in this test is represented by the 1M HCl and the external load is varied to obtain the tensile stress in the specimen: 70%, 56%, 42%, 28% and 14% normalized to their mean values of tensile strength of joint with certain tip angle of filler metal. The time to fail for the three specimens for each varied tip angle are shown in Figure 5 which is retrieved from a complete data as shown in Table 5.

Figure 5 shows the relation between time to fail and the load. The abscissa (independent variable) was presented in percentage to the joint ultimate strength. While it is practically easier but is not for understanding the SCC phenomenon. In Figure 6 the abscissa is represented in absolute value of dead load which converted to the stress applied to the specimen (MPa). Generally sharper tip angle (lower angle in degree) produces stronger SCC resilience shows by longer time to fail. However, the 60° angle showed stronger SCC resilience. When 75 MPa is applied the 60° held on for 2170 minute. The time to fail is decreased for 30°, 90°, 120°, and 150° those are 780, 600, 130 and 35 minutes respectively. Thus, there are two aspects that should be explained: first the sharper tip generally provides better SCC resiliencies and the second the 60° shown a best performance or in another word the 30° did not show highest SCC resilience. Figure 1 shows that, electronically, the CDW process is a closed looped series circuit. Thus, in all parts the current is equal. If it is focused to the wire tip, a narrower cross section means higher current density in the evaluated areas. Since the current density is correlated to the increased temperature in the observed area it is plausible if it is assumed that the part starts to melt begun from an equal cross section area as shown schematically in Figure 7. The volume of the cone with an equal area of bases will be larger for the narrower tip angle which means higher tip angle provide more melting metal to form a joint. With the larger melting metal, it is hoped will be formed a better joint.

Table 4 *Ultimate strength of the CDW joints*

4mm (ER70S - SS400) 8.7 (Kg)					
No	30°	60°	90°	120°	150°
1	29	39,5	28,8	18,7	14,3
2	28,7	35,2	28,8	16,2	13,3
3	35,4	36	29	16,2	13,3
Mean	31,033	36,9	28,867	17,033	13,63

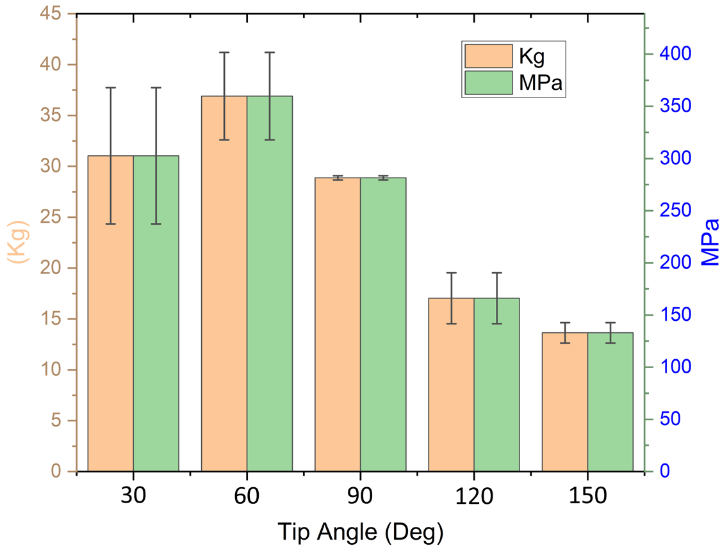

Fig. 4 *Ultimate load*

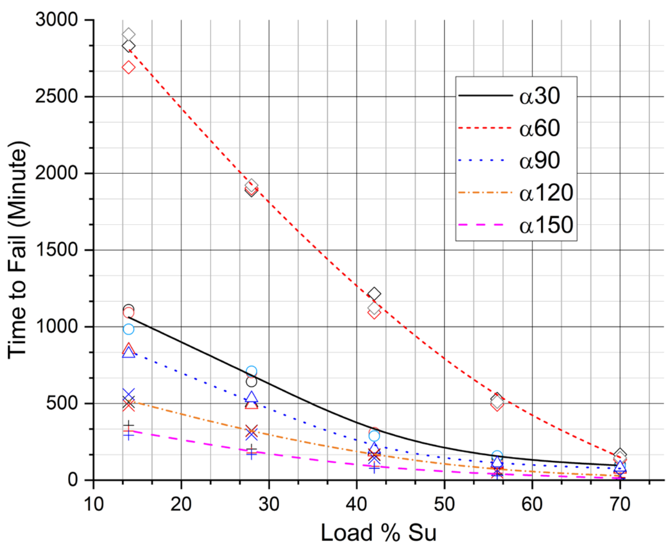

Fig. 5 *Results from SCC test*

Table 5 *The results of the `SCC test*

Variation		Time to fail (minute)				
		Load 70% σ_u	**Load 56% σ_u**	**Load 42% σ_u**	**Load 28% σ_u**	**Load 14% σ_u**
30°	Sample 1	103	144	290	643	1111
	Sample 2	91	110	310	701	1092
	Sample 3	94	158	288	710	984
	Mean	96	137.3	296	684.6	1062.3
60°	Sample 1	167	530	1216	1890	2832
	Sample 2	134	492	1093	1902	2692
	Sample 3	145	511	1123	1923	2807
	Mean	148.6	511	1144	1905	2777
90°	Sample 1	77	98	190	503	851
	Sample 2	69	103	182	491	850
	Sample 3	82	110	201	535	824
	Mean	76	103.6	191	509.6	841.6
120°	Sample 1	30	67	165	323	510
	Sample 2	28	51	169	320	487
	Sample 3	28	67	144	298	560
	Mean	28.67	61.67	159.3	313.6	519
150°	Sample 1	12	37	77	203	357
	Sample 2	17	45	90	177	320
	Sample 3	10	29	78	167	293
	Mean	13	37	81.67	182.3	323.3

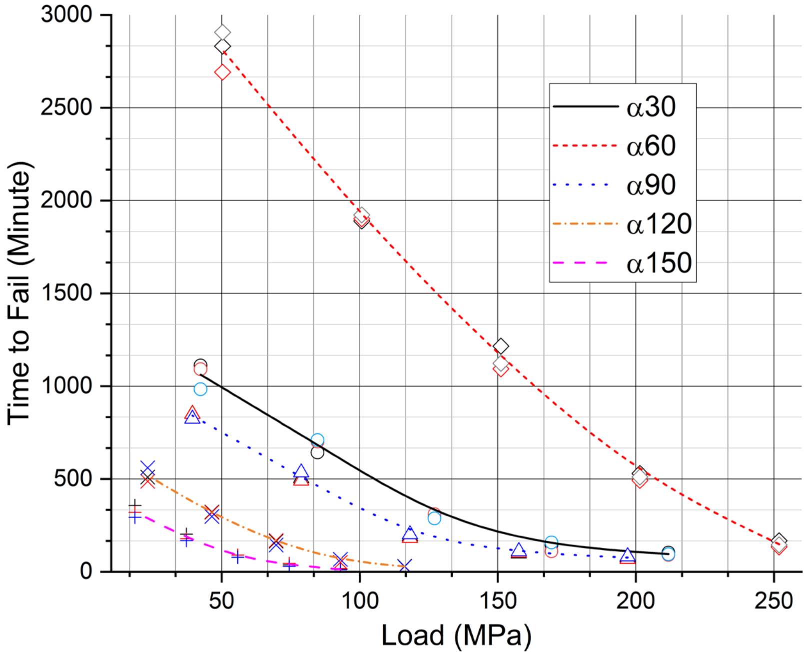

Fig. 6 *Results from SCC test in absolute load*

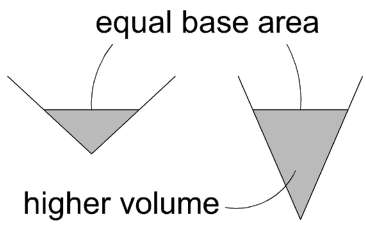

Fig. 7 *Higher available melting metal for sharper wire tip*

This paragraph is explaining why the 30° joints which is the sharpest specimen did not exhibit a best performance. The nature of CDW process in this research, which is shown in Figure 1, shows there is impact pressure force while the CDW joint is applied. With the larger available melting metal, a part of the melting metal is splashed out due to this impact force. Figure 8 shows the macro photo of the broken CDW joint that shown quiet a lot of spatters of the 30° specimen (shown by red circles) which confirmed the above explanation. Due to apart of the melting metal of the 30° specimen does not form the joint; the net volume of the melting metal finally is lower than the 60° and that is why the 30° specimen stand out in shorter period when exposed to the SCC load.

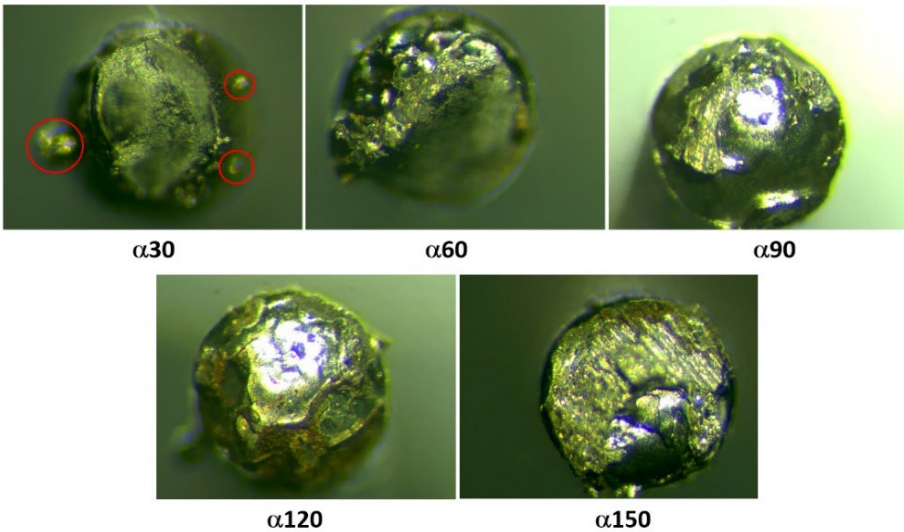

Fig. 8 *The macro photos of the CDW joints*

4. Conclusions

Based on the obtained results it can be concluded that the surface preparation that is forming the wire filler metal tips improved the quality of the CDW joint in terms of SCC resilience. The available volume of the melting metal can be considered as the root cause of the resulting joint quality. There are two phenomenon which should be compromised to obtain the maximum joint quality: the current density and the impact force in the CDW process. Indeed, the sharper wire tip provides larger melting point but too much melting metal will be splashed out while the impact force takes place while the wire is impacted to the SS400 plate. Based on both aspects (current density and impact force) the 60° specimen produce the best CDW joint that provide enough melting filler metal while minimized the spatter formation.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follow: ***study conception and design:*** *Djarot B. Darmadi;* ***data collection:*** *Andika Dewa Satrio;* ***analysis and interpretation of results:*** *Djarot B. Darmadi, Andika Dewa Satrio;* ***draft manuscript preparation:*** *Djarot B. Darmadi, Slamet Prasetyo Utomo. All authors reviewed the results and approved the final version of the manuscript.*

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