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Issue | May 2020

EFFECT OF WELD METAL COMPOSITION AND POST WELD HEAT TREATMENT ON MECHANICAL, CORROSION AND MICRO STRUCTURAL PROPERTIES OF 308L, 309L AUSTENITIC STAINLESS STEEL WELDMENTS

EFFECT OF WELD METAL

This article studies the effect of post weld heat treatment by varying chemical compositions of Austenitic Stainless Steel claddings on carbon steel.

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ABSTRACT

Austenitic stainless steels (ASS) are widely used material in nuclear reactors and power plants because of their good ductility, excellent corrosion resistance and reasonable weld ability. But, to reduce the construction cost of vessels, stainless steel (SS) base metal is replaced by Carbon or low alloy steel and SS was cladded above the carbon steel for corrosion resistance. During cladding or welding, internal stresses are formed in the base metal. To remove those stresses, cladded base metal parts are post weld heat treated at 620°C & 690°C for 1hour. ASS weld metal contains some amount of ferrite to reduce the hot cracking. During Post weld heat treatment ferrite content in the weld metal is transformed into chromium rich secondary phases. These secondary phases make chromium depletion zones around them. The chromium depletion zones led to intergranular corrosion and affect the mechanical properties of the weld metal. The transformations of secondary phases depend on ferrite number of weld metal. Hence, the ferrite number was varied to achieve better mechanical property and corrosion resistance of weld metal. In this work, two different grades (AISI 308L, 309L) of austenitic stainless steel electrodes are manufactured to 6 different types to attain different ferrite number weld metal by changing chemical composition through flux. The properties of undiluted weld metal are evaluated before and after post weld heat treatment condition of 620°C & 690°C for 1hour. This thesis reports the effect of PWHT on impact toughness properties, lateral expansion, ferrite number, corrosion properties and micro structural properties of E308L, E309L weld metals with different ferrite numbers. From this investigation, it is found that mechanical properties of the high ferrite number weld metal drastically changed compared to low ferrite number weld metal.

KEYWORDS: 308L, 309L austenitic stainless steel, ferrite number, post weld heat treatment, impact toughness, micro structural properties

1. INTRODUCTION

Austenitic stainless steel is widely used among stainless steel group because of the properties of easily weldable and formable. They are most easily recognized as nonmagnetic. A literature survey indicates austenitic stainless steel used as electrodes for the welding of heavy structures in ship building, pressure vessels and heavy vehicles, in order to meet the requirement of good impact properties along with adequate strength [1]. Austenitic stainless steel had less than 0.15% carbon, 16 to 28% chromium and 9 to 30 % nickel. Chromium reacts with the atmosphere oxygen and form passive layer of chromium oxide. It prevents the further oxidation and nickel is enhancing the property of the toughness at cryogenic temperature. Austenitic stainless steels are indicated by 200 and 300 series. Austenitic stainless steel weldments are solidified as austenite as their primary phase and small amount of ferrite [2],[3]. This ferrite was act as barrier to hot cracks, small fissures during solidification of weld zone. Fissures size and amount in the weldment is indirectly proportional to amount of ferrite present on the weldment [4]. The most widely used austenite steel electrode is the E308L, E309L also known as 18/9, 22/12 for its composition of 18% chromium, 9% nickel and 22% chromium, 12% nickel. By varying the chemical composition of the 308L, 309L weld metal within the range mentioned in the ASME SEC II, ferrite content is changed. Post weld heat treatment is the stress relieving process and during this process weldment and HAZ is heated near to critical temperature and kept for some time based on material thickness. Then cooled slowly to room temperature during post weld heat treatment strength of the material is increase [5].

The two major problems that arise during depositing of the austenitic stainless steel electrodes are hot cracking and sensitization. Low melting impurities such as sulphur (S), phosphorous (P) are reason for the hot cracking in austenitic stainless steel weld metal. Which tend to penetrate grain boundaries during welding and generating cracks and shrinkage stress during solidification of weldmetal. This problem can be controlled by adjusting the composition of the filler material to obtain a δ-ferrite in the austenite matrix [3]. Heat input or cooling rate of the weld metal also have some influence on the ferrite formation, but chemical composition have more influence on changing ferrite level in weldment compared to heat input [6]. The ferrite provides ferrite-austenite grain boundaries, which are able to control the sulphur and phosphorous compounds and hot cracking.

If austenitic stainless steels will extensively heated or slowly cooled in the temperature range of 450˚C to 850˚C, chromium rich secondary phases like metal carbides, chi phase and sigma phase are precipitate along the grain boundaries of the ferrite in the weldment leading to chromium depletion in the vicinity of the grain boundaries, this phenomenon is called sensitization [7-13]. The chromium depletion vicinity area in the aged material is directly proportional to aged time and temperature [14]. These secondary phases were reduces the Corrosion and mechanical properties like toughness and ductility of the austenitic stainless steel weldment drastically [5], [15], [16]. Some chemical elements like molybdenum, silicon are promotes these secondary phase formation and copper will delays the secondary phase formation [17]. During aging, if ferrite grain boundary has low carbon content, chi and sigma phases will form. Otherwise metal carbides will form before chi and sigma phase formation. Chi phase will fully converted in to sigma phase by long time of aging [11]. This problem is controlled by adjusting the ferrite content and ferrite morphology in the austenite matrix weldment.

2. EXPERIMENTAL WORK 2.1 WELD ASSEMBLY

308L and 309L bare wire is used to produce electrodes in this project work. Chemical composition of the bare wire is showed in the table 2.1. These 2 wires are made in to 6 different austenitic stainless steel ferrite number weld metal by varying the chemical composition through flux. Chemical composition of the 6 different ferrite number weldmetal is shown in the table 2.2. Heat no 1-3 indicates 308L and heat no 4 – 6 indicates 309L weld metal chemical composition. C-Mn steel (IS 2062 grade B) is used as base material and 3.15 × 350 mm austenitic stainless steel electrode was used to make SMAW joints. The chemical composition of the base metal is shown in table 2.3. IS 2062 material is used as base metal for weld assembly, ferrite pad and IGC pad.

C-Mn steel, 15 mm thickness is used for fabrication of single 'V' but joint configuration as shown in Figure 2.1. Welding parameters like root gap, Bevel angle, Interpass temperature, Back plate and Base plate dimensions are selected as per the ASME section II C – SFA 5.4. The base material IS 2062 used in the present investigation at the size of 300mm X 125mm X 15mm and Backing plate of size 370mm X 30mm X6.5mm. The initial joint configuration was obtained by securing the plates in position using tack welding. After tack welding 3mm butter layer is added to base metal to prevent the dilution of the base metal into weld metal. Interpass temperature was maintained at maximum of 150°C. The process parameters used in the fabrication of joints are presented in Table 2.4. Then weld is made Plates are welded in flat (1G) position and DCEP polarity was used.

The welded joints are sliced and machined to required dimensions for preparing impact and micro specimens under (American Society for Testing of Materials) ASTM guidelines.

Table 2.1 Bare wire Chemical Composition

BARE WIRE	%C	%Cr	%Ni	%Mo	%Mn	%Si	%P	%S	%Cu	%Nb	%N
308L	0.022	19.75	9.2	0.176	1.51	0.42	0.028	0.01	0.102	0.02	0.064
309L	0.025	23.48	12.98	0.011	1.83	0.41	0.016	0.01	0.104	0.03	0.084

Table 2.2 308L & 309L electrode Chemical Composition

Table 2.3 Base material Chemical Composition

Heat No	%C	%Cr	%Ni	%Mo	%Mn	%Si	%P	%S	%Cu	%Nb	%N	WRC FN
1	0.036	19.5	9.6	0.103	0.91	0.45	0.034	0.01	0.074	0.038	0.086	4
2	0.037	19.98	9.54	0.065	0.89	0.43	0.039	0.01	0.046	0.038	0.082	7
3	0.032	20.69	9.31	0.235	0.94	0.42	0.033	0.01	0.17	0.04	0.08	11
4	0.03	22.59	13.06	0.304	1.47	0.7	0.027	0.02	0.166	0.047	0.104	6
5	0.037	23.56	12.82	0.302	1.5	0.77	0.017	0.014	0.103	0.042	0.11	9.5
6	0.038	24.47	12.8	0.302	1.58	0.77	0.024	0.024	0.106	0.046	0.106	13

Fig 2.1Weld assembly

%C	%Mn	%S	%P	%Si
0.23	1.5	0.04	0.038	0.4
	Table 2.4 welding parameters			
Heat No	**Current (A)**	**Voltage (V)**	**Average Travel speed (mm/s)**	**Average Heat Input (KJ/S) – MAX**
1	107 – 110	20 – 22	2.17 – 2.35	1.12
2	107 – 110	20 – 22	2.17 – 2.35	1.12
3	107 – 110	20 – 22	2.17 – 2.35	1.12
4	107 – 110	20 – 22	2.17 – 2.35	1.12
5	107 – 110	20 – 22	2.17 – 2.35	1.12
6	107 – 110	20 – 22	2.17 – 2.35	1.12

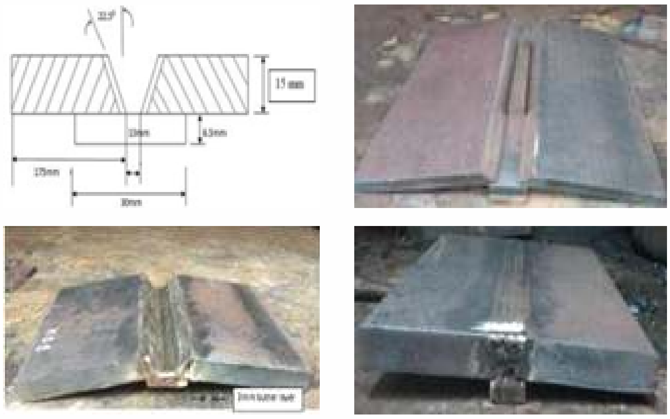

Fig 2.1Weld assembly

2.2Ferrite pad

Ferrite pad is prepared as per the ASME sec II part C SFA-5.4/SFA-5.4M. The ferrite pad is built up between two copper bars laid parallel on the base plate by depositing single weld bead layer by layer. Schematic diagram of ferrite pad is and prepared ferrite pad is shown in fig 2.2.

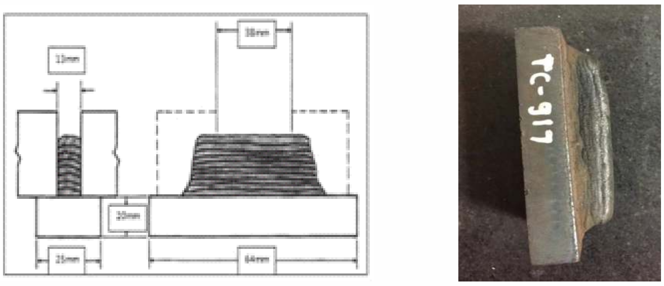

Fig 2.2Ferrite pad

2.3 IGC Pad

IGC pad was prepared by depositing the electrode on the base metal. The pad shall be welded in the flat position, using as short an arc length as practical. Multiple layers are used to obtain undiluted weld metal. Prepared IGC pad was shown in fig 2.3

Fig 2.3 Prepared IGC weld pad

2.4 Post weld heat treatment

After welding weld assembly,IGC specimen and ferrite pad from each heat are subjected to two post weld treatment temperature of 620°C and 690°C for one hour. Fig 2.4 showed the PWHT cycle for weld metals.

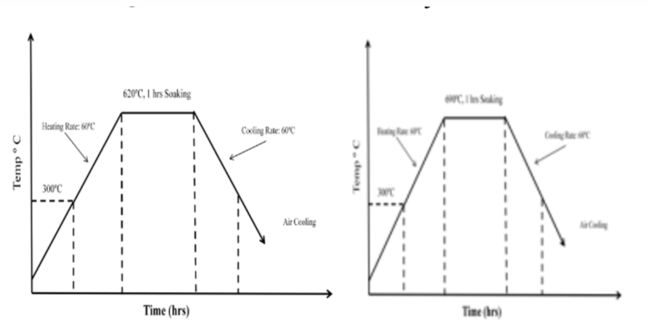

Fig 2.4 620°C & 690°C PWHT Cycle

2.5 Sample preparation

Test samples are prepared with dimensions and tested as per the ASTM E23 standard. From each assembly, impact samples are prepared with specified dimensions. The Charpy impact test was conducted at -20°C using a pendulum type impact testing machine.

The microstructure of weldments was analyzed using a light optical microscope. The specimens after polishing to mirror finish then etched with combination of distilled water – 70ml, HCL – 15ml and HNO3 – 5ml was specified in ASTM E407 is used to reveal the microstructure. IGC specimens are prepared with dimensions mentioned in the ASTM E262 standard and prepared. IGC specimens are shown in fig 2.5. Corrosion rate was measured by following formulae Corrosion rate (Millimeters per month) = $\frac{(7305 \times W)}{(D \times A \times T)}$

Fig 2.5 IGC specimen

3. RESULTS

3.1 Ferrite number

Ferrite numbers of each heat weldments is measured by ferritescope before and after post weld heat treatment and listed in table 3.1. From the results we know that ferrite number of the weld is reduced after post weld heat treatment. Reduction percentage of ferrite number is increase with increasing post weld heat treatment temperature from 620 to 690 °C. It shows that secondary phase formation increased with post weld heat treatment temperature.

In 308L weld metal high amount of ferrite was transformed into secondary phases in high ferrite weldment (FN 11) compared to low ferrite weldment (FN 4). But, During PWHT high percentage of ferrite in the low ferrite weldment (FN 4) will be transformed into 55% of secondary phases compared to high ferrite weldment (FN 11) transformed into only 45 % of secondary phases at post weld heat treatment temperature of 690 °C. In 309L material ferrite reduction rate was high in the high ferrite number weld metal due to high amount of chromium content.

Table 3.1 Ferrite number According to Ferritescope and WRC-1992(FN) Diagram

ELECTRODE TYPE	HEAT NO	FERRITE NUMBER FOR WRC1992 DIAGRAM	Ferritescope		
			As Weld condition	PWHT @ 620°C	PWHT @ 690°C
308L	1	4	7.7	4.5	3.4
	2	7	9.7	6.3	4.7
	3	11	12.8	8.8	6.8
309L	4	6	6.5	5.1	3.5
	5	9	9	6.8	2.9
	6	13	12.6	9.5	2.3

3.2 Impact properties

The Charpy impact toughness value and lateral expansion are observed to all heat at as weld condition and post weld heat treated specimens at - 20°C and found that low ferrite number weld have high toughness compared to high ferrite weld. For each heat number, as welded joints have higher toughness when compared to post weld heat treated weld joints. Ferrite is brittle phase compared to austenite. So toughness was reduced while increasing ferrite content. When the weldment is subjected to post weld heat treatment chromium rich secondary phases like chromium carbide, chi phase and sigma phase are formed. It will reduce the ductility and toughness drastically.

Table 3.2 Impact toughness value at – 20 °C

ELECTRODE TYPE	HEAT NO	FERRITE NUMBER	As weld condition (JOULE)	PWHT @ 620°C (JOULE)	PWHT @ 690°C (JOULE)
308L	1	4	80	68	60
	2	7	74	62	58
	3	11	68	60	56
309L	4	6	63	56	11
	5	9	55	47	08
	6	13	52	38	07

Table 3.2 Impact toughness value at – 20 °C

ELECTRODE TYPE	HEAT NO	FERRITE NUMBER	As weld condition (mm)	PWHT @ 620°C (mm)	PWHT @ 690°C (mm)
308L	1	4	1.35	1.19	1.07
	2	7	1.27	1.11	1.02
	3	11	1.14	1.05	0.94
309L	4	6	1.05	0.91	0.37
	5	9	0.91	0.70	0.33
	6	13	0.82	0.65	0.30

3.5 IGC practice E results

Table 3.4 IGC practice E results

MATERIAL TYPE	HEAT NO	FERRITE NUMBER	As weld condition	PWHT @ 620°C	PWHT @ 690°C
308L	1	4	PASS	PASS	PASS
	2	7	PASS	PASS	PASS
	3	11	PASS	PASS	PASS
309L	4	6	PASS	PASS	FAIL
	5	9	PASS	PASS	FAIL
	6	13	PASS	FAIL	FAIL

Table 3.4 shows IGC practice E results. In 308L all ferrite number electrode at all weld conditions are passed without any fissures and cracks formation in IGC practice E. In 309L all ferrite number electrode weld metal at as weld condition was passed. At post weld heat treated condition of 690°C for 1 hour all ferrite number welds are failed. Because formation of secondary phase was faster in 690°C PWHT temperature compared to 620°C PWHT temperature.

3.6 IGC practice C results

Table 3.5 IGC Practice C results

HEAT NO	FERRITE NUMBER	As weld condition (Mils per year)	PWHT @ 620°C (Mils per year)	PWHT @ 690°C (Mils per year)
1	4	29.765	25.76	28.59
2	7	29.74	29.74	29.85
3	11	27.39	28.85	28.49
4	6	18.882	22.98	17.93
5	9	17.60	19.67	20.31
6	13	17.41	19.85	16.17

Table 3.5 shows IGC practice C results. High ferrite number welds have high corrosion resistance. Because high ferrite welds have high chromium, Due to that passive layer strength is increased and corrosion rate is reduced. 309L weld metal have low corrosion rate compared to 308L material. Because 309L materials have 22 – 25 % chromium and 308L material have 18 – 21 % chromium. Due to high chromium percentage corrosion rate is low in 309L material.

3.6 Microstructure

The microstructure of the joints was examined and optical micrographs taken at weld region are displayed in Figure.3.1, 3.2, 3.3, 3.4, 3.5 & 3.6 at 1000X magnification condition. In 308L weld metal Vermicular ferrite structure is observed in the low ferrite weldment FN 4 and FN 7 (fig 3.1 & 3.2). Lacy ferrite structure is observed in high ferrite weldment FN11 (fig 3.3). In 309L weld metal vermicular ferrite is observed in the low ferrite weld metal FN 6 (fig 3.4), combination of vermicular and lacy ferrite was identified in the medium ferrite weld FN 9 (fig 3.5) and lacy structure was formed in high ferrite weld metal FN 13 (fig 3.6). These ferrite structures in the weldments are demises when weldments are subjected to post weld heat treatment.

Fig 3.1 308L – FN4 weld metal microstructure with different PWHT temperature

Fig 3.2 308L - FN7 weld metal microstructure with different PWHT temperature

Fig 3.3 308L - FN11 weld metal microstructure with different PWHT temperature

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Fig 3.4 309L – FN6 weld metal microstructure with different PWHT temperature

Fig 3.5 309L – FN9 weld metal microstructure with different PWHT temperature

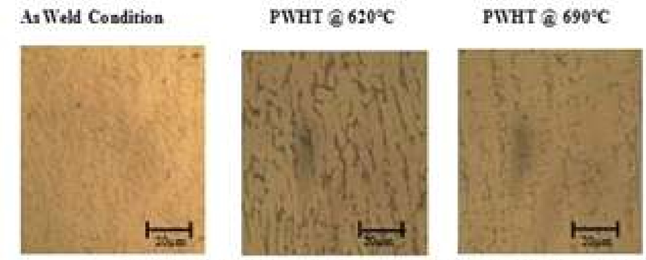

Fig 3.6 309L – FN13 weld metal microstructure with different PWHT temperature

The demised ferrite content in the weld metal was transformed in to chromium rich secondary phases like metal carbides (M23C6), Chi and sigma phase.

4. DISCUSSION

4.1 Effect of weld metal chemical composition and PWHT on ferrite number

In 308L weld metal higher ferrite number is obtained in heat no 3 (table 2.2) and in 309L weld metal higher ferrite number is obtained in heat no 6 with changing the chemical composition of electrode as increasing chromium content and reduce the nickel content. Chromium is the strong ferrite stabilizer, so ferrite content in this weldment is increased. At heat no 1 and 4, low ferrite are obtained reducing the chromium content and increasing nickel content. Ferrite number of each weldment after post weld heat treatment was reduced when compared to as welded condition weldment. Because during post weld heat treatment ferrite content in the weldment is transformed in to secondary phases like metal carbides, chi phase and sigma phases [6-13]. These secondary phases all are non-magnetic. It cannot be measured by ferritoscope. So measured ferrite number value is reduced. Ferrite reduction rate was high in 309L high ferrite weld metal.

4.2 Effect of weld metal chemical composition and PWHT on impact properties

Percentage of ferrite phase in the austenitic stainless steel weld metal plays the important role in changing the toughness and lateral expansion in weld metal. Heat no 1 have high toughness and lateral expansion due to high amount of austenite in the weld metal compared to heat no 2 and 3 (table 3.2 and 3.3). During post weld heat treatment chromium rich secondary phases are precipitated at the ferrite grain boundary and grow towards the centre of ferrite grains [7-13]. These chromium rich phases are very hard and brittle [15, 16]. These phases are restricting the movement of the dislocations in the weld metal during elongation. So, it will reduce the ductility and toughness of the weld metal drastically. Heat no 4, 5, 6 have low impact toughness compared to heat no 1, 2, 3 weld metal. Because heat no 4, 5, 6 have high chromium content (22% -25%). This high chromium content accelerates the secondary phase formation and reduces the toughness drastically to brittle fracture at post weld heat treat condition.

4.3 Effect of weld metal chemical composition and PWHT on microstructure

The weldment of ferrite number 4, 6 and 7 has vermicular ferrite morphology (figure 3.1, 3.2, 3.4) in as weld condition. Low ferrite content is the reason for the vermicular ferrite morphology [17]. Vermicular ferrite has fewer coherencies with the austenite [8]. Due to this high energy grain boundary is formed. When the weld metal is exposed to PWHT the ferrite is transformed into secondary phases and ferrite will demises. Ferrite number 11 weld metal has lacy ferrite morphology (figure 3.3). During PWHT it will transformed in to secondary phases. The demising rate of the ferrite is high at PWHT temperature 690°C when compared to 620°C. Because transformation rate of ferrite is higher at 720°C and 690°C is comparatively near to that temperature [14]. Ferrite number 11 weld metal has lacy ferrite morphology. Lacy ferrite has high degree of grain boundary coherency with austenite [8]. Due to that it has less percentage of ferrite transformation tendency compared to vermicular ferrite structure. So, in the lacy ferrite structure (FN11) 45% of ferrite is transformed in to secondary phases at PWHT at 690°C. But in the vermicular ferrite (FN4) 55% of ferrite is transformed in to secondary phases at PWHT at 690°C. But in 309L weld metal ferrite demises rate is high in lacy ferrite structure (FN 13) compared to vermicular ferrite (FN 6). It clearly shows chromium content in the weld metal also play the major role in the demises of ferrite phase.

4.4 Effect of weld metal chemical composition and PWHT on corrosion properties

In 308l material, high ferrite number weld metal have high corrosion resistance due to high amount of chromium present in the weld metal. Chromium content in the weld metal was further strengthening the passive layer of the weld metal. Due to that corrosion resistance was increased. After post weld heat treatment corrosion rate was reduced in low ferrite weld metal due to stress relive and for high ferrite weld metal corrosion rate was increased due to chromium rich secondary phases formed. These chromium rich secondary phases formed chromium depletion zones. It leads to low resistance to corrosion.

In 309l material also same trend is followed in the as weld condition weld metal. But after post weld heat treatment corrosion resistance was increased. In 309L weld metal also chromium rich secondary phases formed. But due to high chromium content(22- 25%) and diffusion rate of chromium in the weld metal, chromium depletion zones are not formed in the weld metal[14]. Due to that 309L have high corrosion resistance [19].

5. CONCLUSIONS

From this investigation, following conclusions are derived,

1. Ferrite number of weld material was reduced when the material was exposed to PWHT. Reduction percentage of ferrite was high at 690 °C compared to 620 °C. Ferrite was transformed into secondary phases like metal carbides, sigma phase and secondary austenite due to PWHT.
2. The impact toughness, lateral expansion of the weld metal was reduced when the ferrite content of the weld metal was increased. Because ferrite had higher amount of chromium and it reduced the ductility.
3. The impact toughness, lateral expansion of the weld metal was reduced when the weld metal exposed to PWHT due to secondary phases formation. 309L weld metal has low toughness and lateral expansion.
4. Microstructure was analyzed before and after PWHT. The weld metal of low ferrite number microstructure consisted of austenite and vermicular ferrite and high ferrite number have austenite and lacy ferrite morphology.
5. 309L weld metal has high corrosion resistance compared to 308L weld metal. After PWHT 309L corrosion resistance is further increased.

ACKNOWLEDGEMENTS

The authors are thankful to ADOR WELDING, PUNE for providing base material, electrodes and extending fabrication facility for joint fabrication providing testing facilities to carry out this investigation.

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