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Dissimilar Metal Welding of AISI 4130 Steel To 18% NI Mararing Steel

D. Dhanapal, S. Venkateswarlu, B. Jayachandraiah

Abstract: ***Maraging steels are ultra-high strength and high toughness steels used in the rocket motor casing, leaf springs, landing gears etc. They obtain their strength and toughness from precipitation hardening. The strength of AISI 4130 steels is obtained by austenizing followed by quenching and tempering. They obtain their strength from martensite phase transformation. As the heat treatment for the two steels are different due to different hardening mechanisms, an optimum heat treatment needs to be developed to obtain maximum strength for the dissimilar welding of this two materials. Weldments are often made from dissimilar metals in order to satisfy different requirements for performance. A successful weld between dissimilar metals is that it possesses sufficient tensile strength and ductility so that the joint will not fail. In the present work, 18%Ni (250) maraging steel was joined to AISI 4130 low alloy steel by TIG welding with W2 maraging steel filler wire. These dissimilar welds were realized with two different material conditions. The first condition is welding of solutionised maraging steel to hardened and tempered AISI 4130 steel. The second condition is welding of aged maraging steel to hardened and tempered AISI 4130 steel. The dissimilar welds we subjected to non-destructive testing i.e. X-ray radiography and subsequently subjected to different post weld heat treatment cycles depending on the initial material condition. The joints were offered for microstructure and mechanical property evaluations such as ultimate tensile strength, yield strength and % elongation. The model of the specimen was created using the CATIA software. The model was meshed using software ABAQUS. Boundary conditions were given on the finite element model through ABAQUS.***

Keywords: Dissimilar Metal Welding, AISI 4130, MDN 250, 18% Ni Maraging Steel.

I. INTRODUCTION

18% Ni Maraging steels are a class of very low-carbon high alloy steels exhibiting a unique combination of ultra-high strength, excellent fracture toughness and good weldability. The alloy gains its strength from the precipitation hardening of its soft iron-nickel martensite microstructure. As a consequence, it possesses a combination of strength and toughness superior to other high strength steels by employing a relatively simple heat treatment.

AISI 4130 steels come in the category of high strength medium carbon low alloy steels. It is one of the most widely used steels in aircraft construction because of its combination of moderate strength and reasonable ductility in the quenched and tempered conditions. 4130 steels are strengthened by quenching to form martensite and tempered to the desired strength levels.

In the present work, 18% Ni (250) maraging steel was joined to AISI 4130 low alloy steel by TIG welding with W2 maraging steel filler wire. These dissimilar welds were realized with two different material conditions. The first condition is welding of solutionised maraging steel to hardened and tempered AISI 4130 steel. The second condition is welding of aged maraging steel to hardened and tempered AISI 4130 steel. The dissimilar welds were subjected to non-destructive testing i.e., X-ray radiography and subsequently subjected to different post weld heat treatment cycles depending on the initial material condition. The joint characterization studies include microstructural examination and mechanical property evaluations such as ultimate tensile strength, yield strength and % elongation. The model of the specimen was created using the CATIA software. The model was meshed using software ABAQUS. Boundary conditions were given on the finite element model through ABAQUS.

II. OBJECTIVE

War Head Section AISI 4130		P1 & P2 Motors MDN 250		Nozzle Scurt AISI 4130

Circumferential welds

The two materials are selected for the fabrication of rocket motor assembly are AISI 4130 and 18% Ni Maraging steels. The War Head Section (WHS) and Nozzle Scurt are made of AISI 4130 steel and P1, P2 Rocket motors are made of 18% Ni maraging steel MDN 250.

The fabrication of total rocket motor assembly involves welding of WHS to P2 rocket motor and P1 rocket motor to Nozzle Scurt where in dissimilar welding of Maraging steel and AISI 4130 steel with 1.3mm thickness is the primary requirement.

The prime requirement from the designer is the dissimilar weldment between 4130 steel and maraging steel in the final condition should possess yield strength of **900 MPa**.

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III. LITERATURE SURVEY

Heat treatable low-alloy steels

Heat Treatable Low-Alloy Steels (HTLA) has high hardenability and is capable of offering high strengths depending upon the hardening and tempering heat treatments that they have undergone. HTLA steels frequently are welded in the annealed condition. The entire weldment is then heat treated to the desired strength or hardness.

Metallurgical considerations

Under as quenched condition, the material has highest level of strength and hardness. But its ductility is the lowest. This can be explained based on the phase transformation of steels during quenching process, where the lattice structure of steel changes immediately from face-centered cubic (ϒ phase) to a body-centered tetragonal (marten site). At the same time a large amount of distortion occurs during the formation of the platelets of martensite, which leads to rapid increase of strength and hardness. (K.R. Brown [4])

IV. EXPERIMENTAL DETAILS

The materials selected for this study are AISI 4130 steel and 18% Ni maraging steel. The chemical compositions of these materials are mentioned in table. Initially 4130 steel with 2.6mm thickness and 18% Ni maraging steel with 3.1mm thickness were selected. The 4130 steel was subjected to austenizing and tempering heat treatments. Then the quenched and tempered sheets of 4130 and 18% Ni maraging steel in solutionised condition were machined to 1.3mm thickness, which are the actual thickness of Warhead shell and rocket motor. The tensile properties consisting of 0.2% Yield Strength, Ultimate tensile strength and % Elongation of both the materials in different conditions are evaluated.

Table: Chemical composition of the base metals in Wt %

AISI 4130 Material	
Material	**Percentage (%)**
C	0.3
Cr	0.86
Mo	0.25
Si	0.26
Mn	0.48
S	0.02
P	0.019
Fe	Balance

Maraging steel 250	
Material	**Percentage (%)**
C	0.02
Cr	18.9
Mo	8.1
Si	4.9
Mn	0.4
S	0.15
P	0.04
Fe	Balance

Condition of materials prior to welding

The experimentation involves welding the materials in two different conditions. First route is, welding of quenched and tempered 4130 steel to aged 18% Ni maraging steel. Second route is, welding of quenched and tempered 4130 steel to solution annealed 18% Ni maraging steel.

Heat Treatment prior to Welding

The 4130 steel was austinised at 870^0C for one hour, oil quenched and tempering was carried out at different temperatures of 260^0C, 315^0C and 480^0C for one hour soaking with subsequent air cooling keeping in view the mechanical properties of base metal. The hardness and mechanical properties of base materials prior to welding are evaluated.

WELDING

Pre welds cleaning methods: Before welding, the surfaces of the sheets were degreased with the thorough application of acetone using the lint free cotton cloth. Further a zone 25mm from each side of the weld joint was scrupulously cleaned with stainless steel wire brush.

Tack Welding: The sheets were tack welded by giving the distance between the two tacks as 50mm. The root gap of the joint was maintained as zero.

Selection of filler material: For any combination of dissimilar welding, the selection of filler material plays a key role on the final weldment properties. If 4130 steel filler material is used for welding, necessarily a post weld heat treatment of austenizing and tempering is required to be given in order to get 100% base metal (4130) properties. But, it is not feasible to quench the whole rocket motor assembly after welding. From the literature survey is was studied that the maraging steels can be welded to other dissimilar materials such as type 304 (18Cr-10Ni) stainless steel, mild steel, Hy-80 (23/4 per cent Ni-Cr-Mo) and SAE 4340 (13/4 per cent Ni-Cr-Mo) steel.

Table 3.2 Mechanical properties of 13mm thick weld joint between 18Ni 1700 maraging steel and various dissimilar metals (post-weld heat treatment – 3 hr 480^0C)

Metal Being joined	Filler Material	Welding process	Condi-tion	0.2% Proof stress N/mm^2
Mild Steel	INCO-Weld ‘A’	Manual arc	As-welded	390
			Aged	320
HY-80 steel	INCO-Weld ‘A’	Manual arc	As-welded	380
			Aged	400
AISI 4130	INCO-Weld ‘A’	Manual arc	As-welded	390
			Aged	420
AISI 304 stainless	INCO-Weld ‘A’	Manual arc	As-welded	350
			Aged	370
Mild Steel	18% Ni maraging steel (b)	MIG	As-welded	430
			Aged	340
HY-80 steel	18% Ni maraging steel (b)	MIG	As-welded	750
			Aged	740
AISI 4130	18% Ni maraging steel (b)	MIG	As-welded	1010
			Aged	1170
AISI 4130 stainless	18% Ni maraging steel (b)	MIG	As-welded	430
			Aged	420

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The use of a filler wire similar in composition to the maraging steel base material (W_1 filler material) results in segregation of alloying elements, particularly molybdenum and titanium, at the substructure boundaries in the weld fusion zone [5]. During subsequent aging this leads to accelerated austenite reversion. Reduction of molybdenum and titanium contents in the filler metal reduces the segregation effect considerably. The composition of W_1 and W_2 filler wires are shown in the table below.

Material	Filler wire W_1	Filler wire W_2
C	0.01	0.006
Ni	18.9	18.2
Co	8.3	11.9
Mo	4.6	2.5
Ti	0.41	0.16
Al	0.15	0.46
Fe	Bal	Bal

The use of maraging steel as filler material may lead to the following advantages:

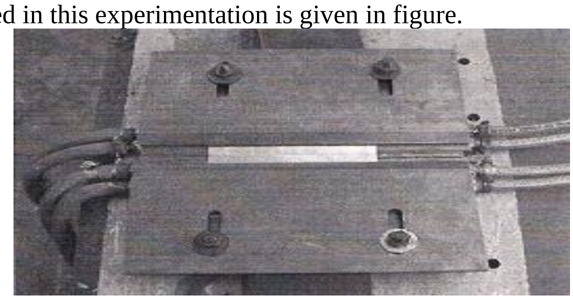
- Metallurgical compatibility (Good fusibility, 0.03%C)
- As welded strength (1000 MPa)
- Near matching post weld Heat treatment cycle between both the materials
- Residual stress pattern (compressive weld residual stresses)

Size of Filler Wire

The size of filler material plays a vital role in deciding the optimum heat input and weld parameters. If the filler wire size increases, the welding current also needs to be increased to melt it. The filler wire diameter is 1mm and the current is 53 to 57 A.

Welding Fixture

The welding fixtures had to provide the intermediate cooling to reduce high heat developed during the welding. A copper base fixture with a facility of continuous water circulation is designed for this purpose. The welding fixture used in this experimentation is given in figure.



Welding parameter:

Mode of welding	Pulsed current
Peak Current: Ip	53 to 57 A
% Break ground current	30 %
% Pulse on time	35 %
Pulse frequency	3 Hz
Voltage	9 to 10 V
Average welding speed	45 mm/min

Non-Destructive Testing:

The weld coupons were subjected to X-Ray radiography test and it was observed that the defects were well within the limits as per acceptance criteria of ASME Boiler and Pressure Vessel code Section VIII Div.2.

Post-Weld Heat Treatment:

These dissimilar welds at different states were subjected to the post weld heat treatments as mentioned below.

- Tempering at 400^{0}C / 1 hours soaking followed by Air cooling for the welding combination of Q & T 4130 steel (tempered at 260^{0}C and 315^{0}C) to aged maraging steel.
- Tempering at 480^{0}C / 1 hours soaking followed by Air cooling for the welding combination of Q & T 4130 steel (tempered at 480^{0}C) to aged maraging steel.
- Heat treating at 480^{0}C / 3 hours soaking followed by Air cooling for the welding combination of Q & T 4130 steel to solution annealed maraging steel.

Dimensions of tensile specimen:

The full size transverse tensile specimens were used in accordance with the ASTM standard E8 for evaluating the mechanical properties. The ultimate tensile strength, 0.2% yield strength and % elongation of the dissimilar weldment at different conditions were evaluated. Room temperature tensile testing was done on INSTRON universal tensile testing machine.

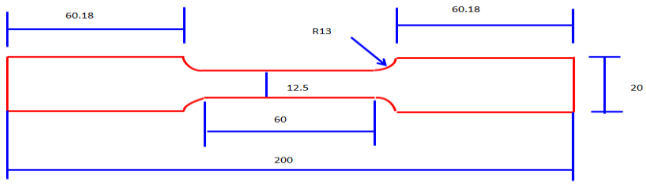


Figure: Drawing Full size Tensile Test Specimen made as per ASTM E8

Evaluation of Microstructure

Leitz optical microscope is used for microscopic examination of different regions of the welds. Magnifications used for studying microstructures were 200X to 500X.

V. RESULTS AND DISCUSSION

The mechanical properties of both the base metals in their solution annealed and heat treated conditions are mentioned in Table 1. The effect of tempering temperature on the mechanical properties of the AISI 4130 steel was studied and the properties are mentioned in Table 2.

Table 1 Mechanical properties of base metals in different conditions

Material	UTS MPa	0.2 % PS MPa	% Elongation
18 Ni Maraging Steel, (Solution annealed)	980	820	18
AISI 4130 steel (annealed)	667	539	30

Material	UTS MPa	0.2 % PS MPa	% Elongation
18% Ni Maraging Steel (aged)	1743	1674	10
AISI 4130 steel (Quenched & Tempered at 260^{0}C)	1680	1468	5.2

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Table 2 Effect of tempering temperature on mechanical properties of AISI 4130

Condition of Base Metal	Tempering Cycle	Tensile Properties			Hard-ness (HRC)
		0.2% PS MPa	UTS MPa	%E I	
Hardened at 870^0C/ 1 hr/Oil Quenched	260^0C, 1hr / AC	1468	1690	5.2	42-44
	315^0C, 1hr / AC	1416	1600	6.0	40-42
	370^0C, 1hr / AC	1415	1577	7.5	38-40
	426^0C, 1hr / AC	1294	1387	8.5	36-40
	480^0C, 1hr / AC	1123	1208	10	34-38

Dissimilar welds between Q&T 4130 steel to aged maraging steel

The tensile properties of dissimilar weldment for the combination of Q&T 4130 steel (tempered at 260^0C, 315^0C and 480^0C) to aged managing steel in the as welded condition and in post weld heat treated conditions are mentioned in table.

Condition of Metals before welding	Post-weld Heat Treatment	Tensile Properties			Failure Loc-ation
		0.2% PS MPa	UTS MPa	% EI	
AISI 4130 (tempered At 260^0C) + MDN 250 (H.T)	As welded	942	1041	2.84	AISI 4130
		941	1053	2.9	
		943	1040	2.76	
	400^0C/ 1 Hr/AC	957	1014	2.8	AISI 4130
		---	997	2.84	
		938.4	1008	3.0	
4130 (H.T) (tempered at 315^0C) + MDN250 (H.T)	As Welded	1087	1190	2.2	AISI 4130
		949	1013	2.1	
		955	1073	2.4	
	480^0C/ 1Hr/AC	1003	1055	2.9	AISI 4130
		979	1029	2.8	
		982	1042	3.1	
4130(H.T) (tempered at 480^0C) + MDN250 (H.T)	As Welded	1042	1152	3.3	AISI 4130
		1012	1022	2.5	
		1069	1100	3.2	
	Post weld 480^0C/ 1Hr/AC	932	984	2.9	AISI 4130
		893	949	3.2	
		890	942	3.0	

Dissimilar welds between Q&T 4130 steel to solution annealed maraging steel

The tensile properties of dissimilar weldment for the combination of Q&T 4130 steel to solution annealed maraging steel in the welded condition and in post weld heat treated conditioned are mentioned in table.

Condition of Metals before welding	Post weld Heat Treatment	Tensile Properties			Failure Loc-ation
		0.2% PS MPa	UTS MPa	%EI	
4130(H.T) (tempered at 260^0C) + MDN250 (Solution annealed)	Maraged (480^0C/ 3Hr/AC)	992	1040	2.4	AISI 4130
		907	937	2.5	
		980	1026	2.5	
4130(H.T) (tempered at 315^0C) + MDN250 (Solution annealed)	Maraged (480^0C/ 3Hr/AC)	912	1012	3.6	AISI 4130
		927	987	3.6	
		894	1007	3.7	
4130(H.T) (tempered at 480^0C) + MDN250 (Solution annealed)	Maraged (480^0C/ 3Hr/AC)	1050	1113	2.4	AISI 4130
		1083	1113	2.5	
		1004	1064	2.5	

Microstructure

Microstructures of parent material are shown in fig.1. The microstructure of AISI 4130 steel (annealed) consists of coarse lamellar pearlite (dark areas) in a matrix of ferrite (white) (fig 1 a).The microstructure of maraging steel (solution annealed) (fig 1 b).The microstructures of parent metals at various heat-treated condition are shown in Fig 4.2.The microstructure of AISI 4130 steel after heat treatment consists of tempered martensite(mixture of plate and lath martensite) (fig 2 a,b,c) and micro structured of MDN 250 after aging consist of aged low-carbon martensite(fig 2 d).

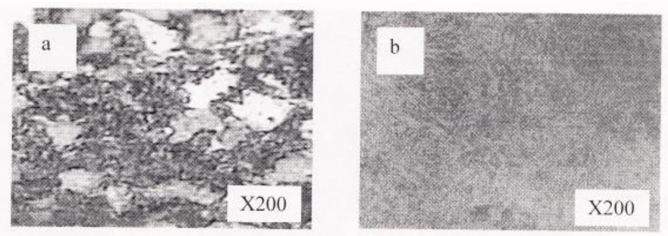

Fig. 1 Optical microstructure of the as received parent metals a) AISI 4130 b) MDN 250

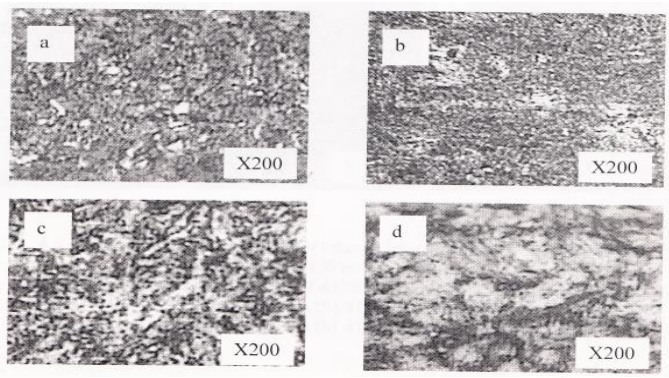

Fig. 2 Microstructure of parent metal at various heat-treated conditions

a) AISI 4130 Quenched and Tempered at 260^0C / 1 hr
b) AISI 4130 Quenched and Tempered at 315^0C / 1 hr
c) AISI 4130 Quenched and Tempered at 480^0C / 1 hr
d) MDN 250 Aged at 480^0C / 1 hr

Analysis using Abaqus

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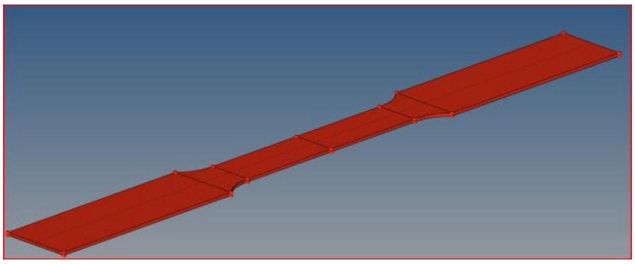
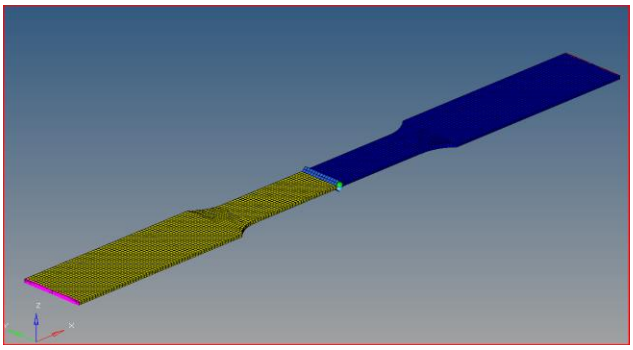


CAD Model



FEM Model

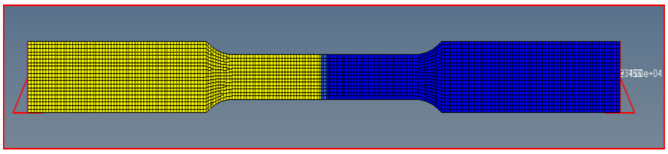
This model is constructed using the following element types:

- C3D8R- Hexa
- C3D6- Penta
- BEAM Elements- 1D
- M3D3 & M3D4 – Membrane section

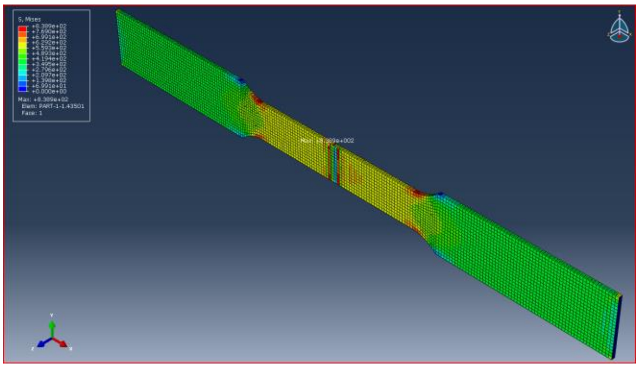
Element Size = 1mm

Materials and their properties

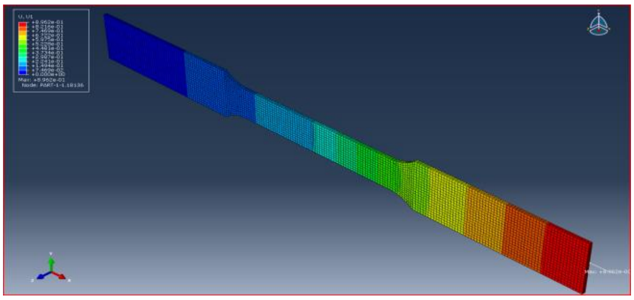
Material	Density	Young's Modulus	Poisson's Ratio
18% Ni Maraging Steel	7.86E-09	210000.0	0.30
AISI 4130	8.10E-09	205000.0	0.29



Loads and Boundary Conditions



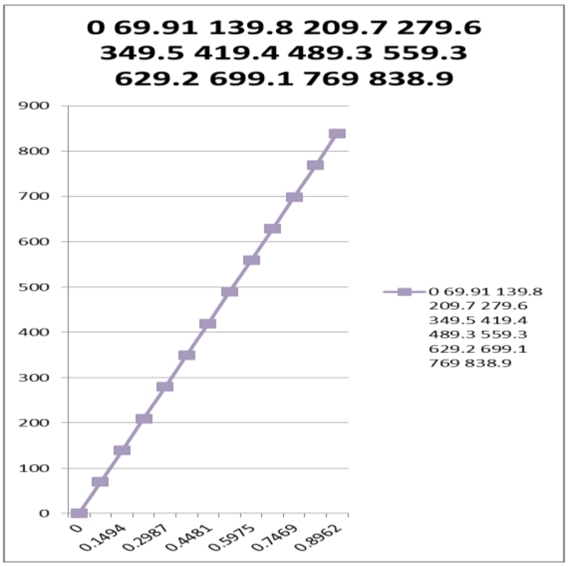
Contour Plot –Stress



Contour Plot –Displacement

Results and Comparison

Displacement (mm)	Stress (MPa)
0	0
0.07469	69.91
0.1494	139.8
0.2241	209.7
0.2987	279.6
0.3734	349.5
0.4481	419.4
0.5228	489.3
0.5975	559.3
0.6722	629.2
0.7469	699.1
0.8216	769
0.8962	838.9



VI.CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Dissimilar welding between maraging steel and 4130 steel is feasible and a radio graphically sound joint can be achieved.
- W2 maraging steel filler wire to be used to weld these dissimilar materials.
- The preferable diameter of the filler wire is 1 mm for welding 1.3 mm thick Rocket Motor Assembly.

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- TIG welding should be performed in pulsed current mode with copper fixture and with continuous water cooling.
- All the specimens have failed in the HAZ portion of 4130 base metal for the dissimilar combination of 4130 (Q&T) and maraging steel (aged).
- Possible sequences of welding and heat treatment of dissimilar materials to achieve 900MP yield strength for dissimilar weldment.
- Pulsed TIG welding of Maraging steel (Solution annealed, 32 HRC) to 4130 (Quenched 870^0C, 1 Hr/OQ& tempered at 260^0C, 1 Hr/AC to 42-HRC) with post weld heat treatment cycle of 480^0C , 3 Hr, AC.
- Pulsed TIG welding of Maraging steel (aged, 48-50HRC) to 4130 (Quenched 870^0C, 1 Hr/OQ& tempered at 260^0C, 1 Hr/AC to 42-44HRC) with poste weld heat treatment cycle of 400^0C, 1 Hr, AC.

SCOPE OF FUTURE WORK

- In the dissimilar welding the residual stress developed during welding is different for each metal. Residual stress can be measured in as welded and in post weld heat treated conditions. Reduction of residual stress after heat treatment in each metal can be found, which might be the cause for failure of joint. Micro hardness across the weldment can be measured for every 0.5mm to find the soft area in the metal due to HAZ and can be compared with micro structural changes in that area.

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