© 2016 IJSRSET | Volume 2 | Issue 2 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Experimental Investigation on Flame Straightening of Corrosion Resistant Structural Steel Sheet Used for Rolling Stock

K B Jayan[1], J. Pradeep Kumar[2]

[1]QA Division, RITES LTD, Chennai, Tamil Nadu, India
[2]Department of Production Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India

ABSTRACT

Flame straightening is a common procedure used for repair work in steel components. It is based on heating a local region of the part by means of a flame torch. Due to the obstruction of the heat expansion, upsetting occurs in the work material. During cooling of the squashed zone shrinkage occurs and that is associated with tension forces which lead to the desired deformation. This process is used in railway shell manufacturing to achieve desired undulation levels of the outer shell skin material. The process of flame straightening suffers from several shortcomings that have strong impacts on the quality, safety and on the economy of railway shell construction. In this paper, a study on the oxyacetylene flame heating of 2mm thick corrosion resistant structural steel sheets (Indian Railway Standard Specification No. M 41 (IRS:M – 41)) is carried out. During heating of IRS:M41 structural steel, an exceeding of oxy acetylene pressure, torch nozzle diameter and the holding time have detrimental effects on mechanical and micro structural properties. The relationship between the micro structural features, tensile and yield strength, elongation and Vickers hardness of material at different combinations of the above parameters were analysed and results were correlated. Based on the experimental results, this study reveals the consequences of flame straightening on microstructure and mechanical properties of the work material influenced by oxy acetylene pressure, torch nozzle diameter and the holding time.

Keywords: Corrosion resistant structural steel, IRS: M41, Undulation, Tin canning effect, Oxyacetylene flame straightening, Microstructure, Mechanical properties

I. INTRODUCTION

Flame straightening is a repair procedure in which controlled heat is applied in specific patterns to the plastically deformed regions of steel in repetitive heating and cooling cycles to gradually straighten the material. D Schafer [1] stated that the flame straightening process is used to achieve the desired geometry of a steel construction element and is almost a matter of empirical craftsmen-knowledge and thus neither really explained nor quantified, although the physical background is highly scientific. The process relies on internal and external restraints that produce thickening or upsetting during the heating phase and in–plane contraction during the cooling phase. Heat straightening is distinguished from other methods is that force is not used as the primary instrument of straightening. The spot heating process lead to thermal expansion or contraction and is an unsymmetrical process. Each such cycle leads to a gradual straightening of heated area. The process is characterized by the following conditions which must be maintained: The temperature of the steel does not exceed either the lower critical temperature (the lowest temperature at which molecular changes occur) or the temper limit for quenched and tempered steels; The stresses produced by applied external forces do not exceed the yield stress of the steel in its heated condition; The heating shall be done only the regions nearby the plastically deformed zones. When these conditions are met, the material properties undergo relatively small changes and the performance of the steel remains essentially unchanged after flame straightening. If the process is properly conducted, flame straightening is a safe and economical procedure for repairing damaged

steel. The hot mechanical straightening differs from flame straightening is that the external force is applied after heating to straighten the damage. These applied forces produce stresses well above yield, resulting in large deformation during a single heat cycle. The results of this type of straightening are unpredictable and little research has been conducted on this procedure. The corrosion resistant structural steel sheets (Indian Railway Standard Specification No. M 41 (IRS:M – 41)) [2] are used for the fabrication of end wall, side wall and roof of railway coaches. The oxyacetylene flame straightening is used in railway shell manufacturing to stiffen the side and the end wall panels of the shell to remove tin canning effect and to maintain the undulation levels within $\pm$ 1.5mm for every 1200mm length [3]. The factors affecting the properties of base metal used in shell fabrication are the straightening temperature, heating cycle time, cooling rate, heating torch diameter and the holding time [4]. These parameters can cause possible effect on the transformation characteristics those results in microstructure of the base metals. Also the fatigue life of the metal can be shortened due to flame straightening as the combination of parameters can affect the mechanical properties of the material and possible micro-cracking at the heated zone. The flame straightening parameters can act singly or a combination with one another to influence the base metal properties [5-13].

II. METHODS AND MATERIAL

Indian Railway Standard Specification No. M 41 (IRS M41) 2 mm thick corrosion resistant structural steel (Heat No. S12395A) of Grade 1 sheets manufactured through cold rolling process are used for experimental work [2]. The chemical compositions of work material are shown in Table 1 and mechanical properties are shown in Table 2.

Table 1. Chemical composition (% wt.) of IRS:M41 Grade 1 steel [2]

C	Mn	P	S	Si	Al	Cu
0.10 Max	0.25 - 0.45	0.075 – 0.14	0.03 Max	0.28 – 0.72	0.08 Max	0.3 – 0.6

Nb	Ni	Cr	V	Mo	Total Incidental Elements (TIE) (Al+V+Mo+Nb)
0.04 Max	0.2 – 0.47	0.35 – 0.6	0.05 Max	0.05 Max	0.15 Max

Table 2. Mechanical properties of IRS : M41Grade 1 steel [2]

Parameters	Requirement as per specification
Tensile strength	440 MPa (Minimum)
Yield strength	300 MPa (Minimum)
Elongation	26% (Minimum)
Bend test	Shall not show any crack outside bend after 180^0/1t bend test

A. Experimental Details

The manufacturing of steel shall be by electric, basic oxygen or a combination of these processes. The steel is available in two grades viz. Grade -I and II. Grade I is intended for structural purpose where guaranteed mechanical properties, weldability and suitability for forming simple cold pressed parts are required whereas Grade – II is intended for general engineering purpose with guaranteed mechanical properties and weldability [2]. Types of welding electrodes used for the fabrication process [19], spot heating techniques on large structures, thermal and stress analysis of sheet metals in welding and various techniques on reduction in welding distortion were analysed [1], [20],[22] and the details are used for conducting experiments. Samples of work material for experiments are taken from the stock as received and are cut in direction of rolling. Oxyacetylene flame spot heating done on the selected samples. Combination of factors were selected as shown in Table 3 and levels of each factors are mentioned based on Taguchi orthogonal array (L9) as shown in Table 4 [14]. The chemical composition of raw material used for experiments is determined by optical emission spectroscopy (OES). The raw material analysis is done to assess the conformity of the material to the specification [2]. The mechanical test specimens are prepared in accordance with Indian Standard for metallic materials [15]. The mechanical properties and Vickers hardness tests are performed on samples under as-received (AR) and after heating (AH) conditions. These tests were carried out on universal testing machine (UTM). The samples for Bend test are prepared based on the direction of rolling. The rough edges resulting from shearing are removed by filing and Bend tests are conducted based on the methodology mentioned in Indian Standard for conducting Bend test [16]. For microstructure analysis,

small coupons are cut in the direction of rolling from the flame heated samples and from the non-heated – as received (AR) condition. As the samples are too small, additional metal pieces are joined on the non-heat affected area by using metal glue. This helped to hold the samples during grinding, polishing and etching operations. Grinding the samples with different polishing papers having size of 80, 120, 240, 320, 400, 600 followed by polishing by using silivite cloths are done during sample preparation. After grinding and polishing upto mirr`or finish, samples were etched with Nital (alcohol and 5% nitric acid) [17] in order to reveal the microstructure. The microstructure of steel samples is examined by optical microscopy (OM).

Table. 3 Experimental parameters and their levels

Factor	Designation	Level 1	Level 2	Level 3
Heating torch tip size	A	3	13	20
Gas pressure in bar (Oxygen/Acetylene)	B	1.5/0.1	2.5/0.21	3/0.28
Holding Time (sec)	C	4	5	6

Table. 4 Design matrix (L9 Orthogonal Array) [14]

S. No	Heating torch tip size	Gas pressure in bar (Oxygen/Acetylene)	Holding Time (sec)
1	3	1.50/0.14	6
2	3	2.50/0.21	5
3	3	3.00/0.28	4
4	13	1.50/0.14	5
5	13	2.50/0.21	4
6	13	3.00/0.28	6
7	20	1.50/0.14	4
8	20	2.50/0.21	6
9	20	3.00/0.28	5

B. Experimental Results

Various tests are carried out using samples of the prepared steel specimens and the results obtained are discussed below. The experimental trials are conducted based on Taguchi L9 orthogonal array.

Chemical composition

The chemical composition obtained for the as received sample of Cold rolled Grade 1 Corrosion Resistant Structural steel (Heat No. S12395A) is given in Table 5. The results show that the composition satisfy the requirement and are within the specified limits mentioned in the material specification [2] as shown in Table 1.

Mechanical Characterisation

The experimental investigation includes the comparison of tensile tests and Bend tests performed on the as received sample and after heated samples. Two trials were carried out in each case and average values are calculated. The results obtained for the as received sample is mentioned in Table 6. The results are compared with the specification [2] and found complying with the standards.

Samples are cut in direction of rolling and the samples are heated with oxyacetylene flame as per combination of factors selected as shown in Table 3 and the levels for each factors used in the experimental trials are based on orthogonal array (L9) as mentioned in Table 4 [14]. Mechanical test specimens prepared in accordance with Indian Standard for metallic materials [15]. Two samples were made in each combination and two trials are carried out. The average of experimental values calculated and presented. The tests are performed at room temperature at a straining speed of 5mm/min. The obtained values of mechanical properties viz. tensile test, yield stress, and elongation are summarized in Table 7.

Table 5: Obtained chemical composition (% wt.) of steel sample

C	Mn	P	S	Si	Al	Cu	Nb	Ni	Cr	V	Mo	T.I.E
0.09	0.39	0.088	0.018	0.32	0.004	0.32	0.001	0.37	0.55	0.001	0.001	0.007

Table. 6 Mechanical properties before flame heating

Parameters	Values obtained		
	Trial 1	Trial 2	Average
Tensile strength	483 MPa	491 MPa	487 MPa
Yield strength	376 MPa	365 MPa	370.5 MPa
Elongation in %	36 %	38 %	37 %
Bend test	Pass	Pass	Pass

III. RESULTS AND DISCUSSION

Table. 7 Experimental strength values obtained for structural steel after flame heating

Heating torch tip size	Gas pressure in bar (Oxygen/ Acetylene)	Holding Time (sec)	Tensile strength in MPa			Yield strength in MPa			Elongation in %		
			Trial 1	Trial 2	Average	Trial 1	Trial 2	Average	Trial 1	rial 2	Average
3	1.50/0.14	6	488	490	489.00	372	371	371.50	36	35	35.50
3	2.50/0.21	5	489	492	490.50	370	372	371.00	36	37	36.50
3	3.00/0.28	4	488	490	489.00	371	374	372.50	33	35	34.00
13	1.50/0.14	5	445	442	443.50	348	344	342.50	38	41	39.50
13	2.50/0.21	4	436	435	435.50	340	342	341.50	42	42	42.00
13	3.00/0.28	6	439	437	438.00	342	343	342.50	46	42	44.00
20	1.50/0.14	4	432	433	432.50	336	342	338.00	44	41	42.50
20	2.50/0.21	6	434	428	431.00	344	346	345.00	45	46	45.50
20	3.00/0.28	5	437	439	438.50	330	333	331.50	42	44	43.00

The Variation of test results obtained from the raw material is mentioned in Table 8. The comparison of results obtained in tensile strength, yield strength and elongation values for as received and after heating samples are shown in Figure 1, 2 and 3 respectively.

Table. 8 Tensile tests experimental results

Heating torch tip size	Gas pressure in bar (Oxygen/ Acetylene)	Holding Time (sec)	Tensile strength in MPa			Yield strength in MPa			Elongation in %		
			As received	After heating	Variation (%)	As received	After heating	Variation (%)	As received	After heating	Variation (%)
3	1.50/0.14	6	487	489.50	+0.51	370.50	371.50	+0.27	37	35.50	-4.05
3	2.50/0.21	5	487	490.50	+0.71	370.50	371.00	+0.13	37	36.50	-1.35
3	3.00/0.28	4	487	489.00	+0.41	370.50	372.50	+0.53	37	34.00	-8.11
13	1.50/0.14	5	487	443.50	-8.93	370.50	342.50	-7.55	37	39.50	+6.75
13	2.50/0.21	4	487	435.50	-10.57	370.50	341.50	-7.82	37	42.00	+13.51
13	3.00/0.28	6	487	438.00	-10.06	370.50	342.50	-7.56	37	44.00	+18.90
20	1.50/0.14	4	487	432.50	-11.29	370.50	338.00	-8.77	37	42.50	+14.86
20	2.50/0.21	6	487	431.00	-11.49	370.50	345.00	-6.88	37	45.50	+22.97
20	3.00/0.28	5	487	438.50	-9.95	370.50	331.50	-10.52	37	43.00	+16.21

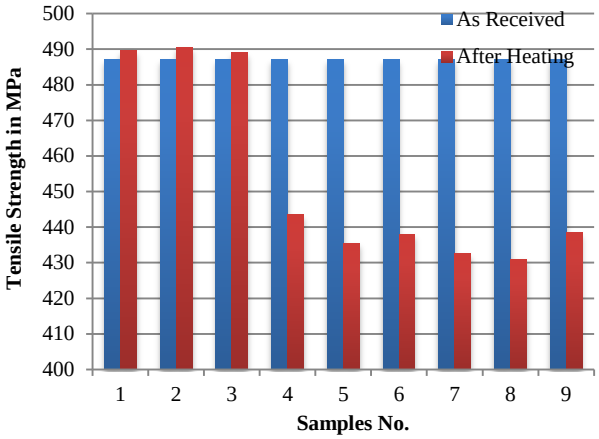


Figure 1. Variation in tensile strength values

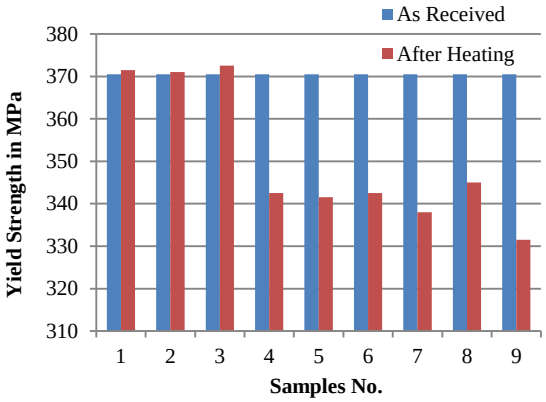


Figure 2. Variation in yield strength after heating the samples from the parent material

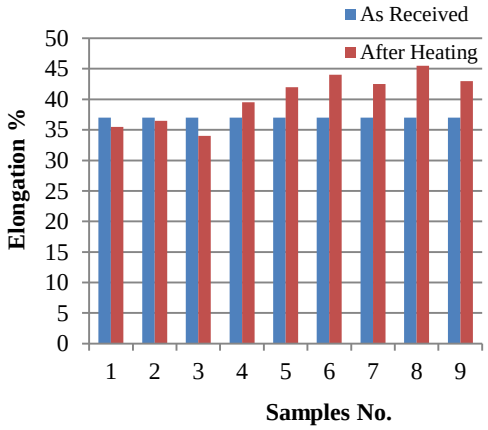


Figure 3. Variation in % elongation after heating the samples from the parent material

The Vickers hardness test (30 kgf, 20s) is performed on the flame heated samples. The results of Vickers hardness test carried out at the centre of the heated spot, 5mm and 10mm away from the centre of the heated spots are shown in Table 9. The variation in Vickers hardness for different heated samples is shown in Figure 4.

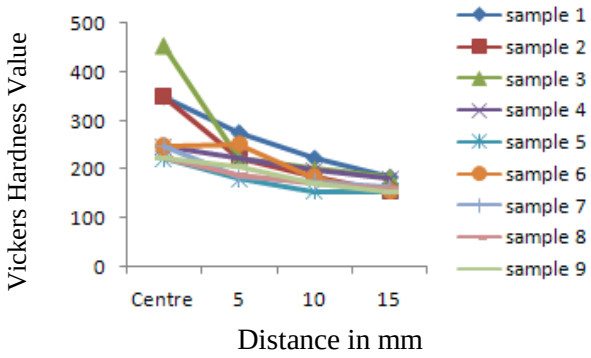


Figure 4. Variation in Vickers hardness values

The bend test results obtained for all the 10 samples including raw material are mentioned in Table 10.

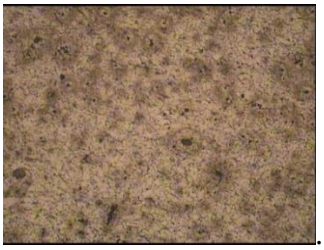
Table. 9 Summary of results of Vickers hardness test

Heating torch tip size	Gas pressure in bar (Oxygen/ Acetylene)	Holding Time (sec)	Vickers Hardness (VHN). Applied load 30 Kgf, 20s			
			Centre of the heated spot	5 mm from centre	10 mm from centre	15 mm from centre
3	1.50/0.14	6	347.62	274.67	222.48	183.87
3	2.50/0.21	5	347.62	222.48	183.87	154.50
3	3.00/0.28	4	454.04	222.48	200.43	183.87
13	1.50/0.14	5	246.52	222.48	198.48	180.48
13	2.50/0.21	4	222.48	180.46	154.52	154.50
13	3.00/0.28	6	247.62	252.28	183.87	154.50
20	1.50/0.14	4	248.68	183.87	175.28	163.87
20	2.50/0.21	6	222.48	188.85	170.66	160.82
20	3.00/0.28	5	222.48	206.41	170.56	154.50

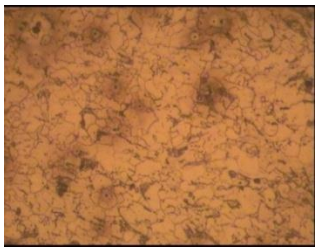
Table 10. Bend test results

Heating torch tip size	Gas pressure in bar (Oxygen/Acetylene)	Holding Time (sec)	Observation	Remarks
3	1.50/0.14	6	No visible cracks observed	Pass
3	2.50/0.21	5	No visible cracks observed	Pass
3	3.00/0.28	4	No visible cracks observed	Pass
13	1.50/0.14	5	Visible cracks observed	Fail
13	2.50/0.21	4	Visible cracks observed	Fail
13	3.00/0.28	6	Visible cracks observed	Fail
20	1.50/0.14	4	Visible cracks observed	Fail
20	2.50/0.21	6	Visible cracks observed	Fail
20	3.00/0.28	5	Visible cracks observed	Fail

The microstructure of As- received and After-Heating samples are analysed with OM. Two macrographs of as received samples with different magnification are shown in Figure 5. The microstructure reveals fine ferrite grains. The material is in cold rolled condition. The Figures 6 to 14 show the microstructure of the sample numbers from 1 to 9 prepared as per the factors mentioned in Table 4. In all cases microstructure at three locations viz. at centre, 5mm from centre and 10mm from centre were examined by OM.



(a)



(b)

Figure. 5 Macrographs showing microstructure of non-heated sample
with (a) 100X and (b) 400X magnification

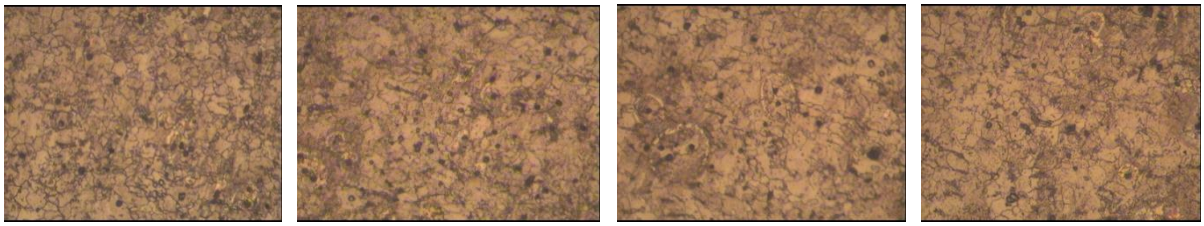
Results and discussion from microstructure study

The microstructure at the centre of heated spot for sample No. 1 (Figure 6 (a)) revealed uniformly distributed fine grains of pearlite (black) and ferrite (white) matrix. 5mm, 10mm and 15mm from centre

of first sample (Figure 6 (b), (c) and (d)), structure consist of fine dispersion of alloy carbides in a matrix of coarser ferrite. For sample No.2, at centre (Figure 7(a)) structure consists of ferrite and pearlite. Elongated grains are seen whereas 5mm from centre (Figure 7 (b)) structure consists of equiaxed fine ferrite and pearlite. 10mm & 15mm from centre of sample No. 2, (Figure7 (c) & 7(d)), structure revealed fine pearlite and coarser ferrite grains. Figure 8 (a) shows microstructure of sample No.3 at centre. Structure revealed ferrite and lower bainite in tempered martensite. Figure 8(b) reveals blocky ferrite & pearlite structure at 5mm from centre of sample No. 3. Figure 8(c) and 8 (d) - structure consist of coarser ferrite and moderately banded pearilite 10mm & 15mm from centre of sample No.3. Figure 9 (a) shows microstructrure at the centre of sample No. 4. Pearlite colonies with ferrite partially outlining the prior austenite grain boundaries are seen. Figure 9 (b) - Structure consist of equiaxed fine ferrite and pearlite at 5mm from centre. Figure 9(c) and 9(d) - Structure consist of pearilite and ferrite grains at 10mm and 15mm from centre of the heated spot. Grains are slightly coarser and non equiaxed. Figure 10 (a) revels structure for sample No. 5 at centre. It consists of ferrite and pearlite. Grains are slightly elongated. 5mm from centre location (Figure 10(b)) shows pearlite colonies with ferrite partially outlining the prior austenite grain boundaries. Figure 10 (c) and 10(d) shows 10mm and 15mm from centre of sample no. 5. Coarser grains structure of pearilite and ferrite observed. Figure 11 shows microstructure of sample No.6 Severely overheated specimen at center shows (Figure 11 (a)) initial stage of "burning". Figure 11(b), 5mm from centre revealed ferrite at prior austenite grain boundaries and within grains. Large amount plates of ferrites also seen. Over heat affected location. Figure 11(c) and 11 (d) – 10mm and 15mm from centre of heated zone, uniformly distributed pearilite in ferrite matrix is seen. For sample No.7, centre portion (Figure 12(a)), structure consist of fine dispersion of alloy carbide in a matrix of ferrite. Figure12 (b), 5mm away from centre, uniformly distributed pearlite in ferrite matrix is seen. 10mm and 15mm from centre (Figure 12 (c) and 12 (d)) structure consists of fine dispersion of alloy carbide in a matrix of coarser ferrite. Centre of sample No.8 (Figure 13 (a)) the structure consist of fine grains of ferrite. Figure 13(b) shows location at 5mm from centre. Structure consist of ferrite and pearlite. Pattern of pearlite reflects dendritic segregation of cabon and alloying elements. 10mm & 15mm from centre (Figure 13 (c) and 13(d)) - Structure consist of fine dispersion of alloy carbide in a matrix of coarser ferrite. For sample No. 9, at centre (Figure 14(a)) – Structure revealed ferrite and lower bainite in tempered martensite. 5mm from centre (Figure 14(b)) - Structure consist of equiaxed fine ferrite and pearlite. 10mm and 15mm from centre (Figure 14 (c) and 14(d)) - structure revealed coarser pearlite and ferrite. The relation between yield strength and grain size is described mathematically by the Hall–Petch as shown in equation 1.

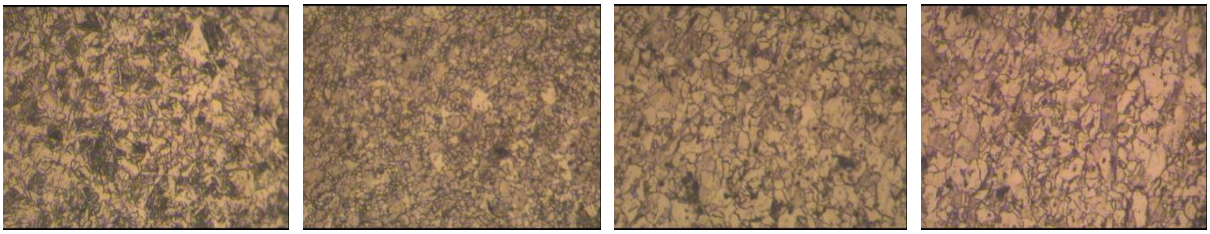
$$\sigma_y = \sigma_o + \frac{k_y}{\sqrt{d}} \quad \text{---------- (1)}$$

where σ_y is the yield strength, σ_o is a materials constant for the starting stress for dislocation movement (or the resistance of the lattice to dislocation motion), k_y is the strengthening coefficient (a constant unique to each material), and d is the average grain diameter. The Hall–Petch relation predicts that as the grain size decreases the yield strength increases and vise versa.



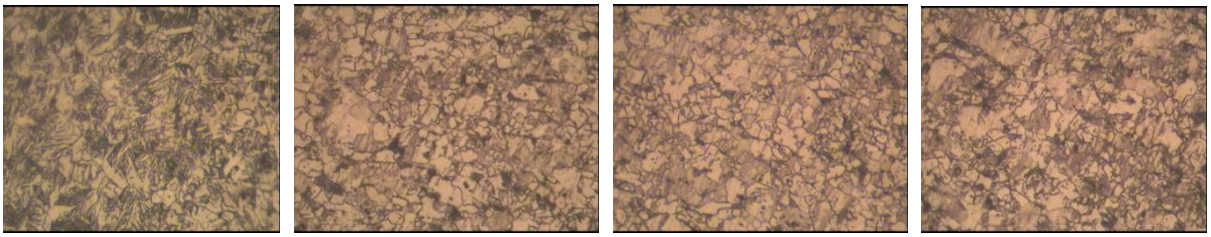
(a) (b) (c) (d)

Figure. 6 Macrographs of showing micro-structure of heated Sample No. 1 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



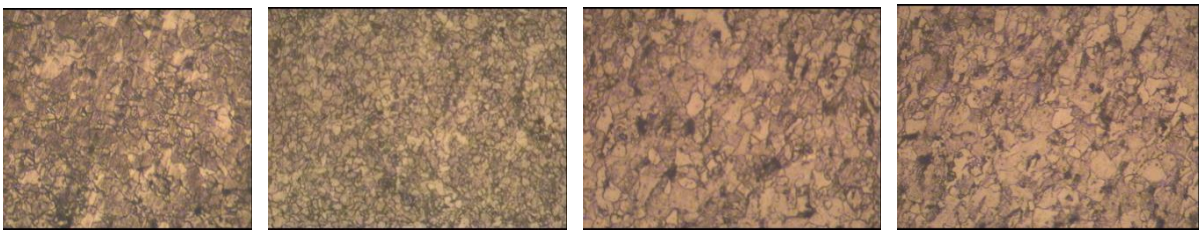
(a) (b) (c) (d)

Figure. 7 Macrographs of showing microstructure of heated Sample No. 2 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



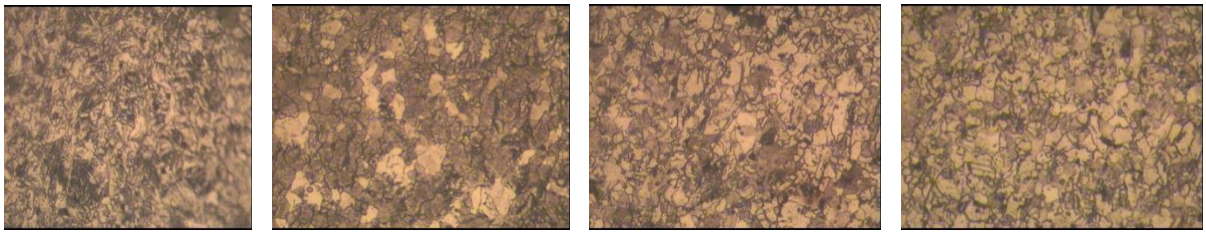
(a) (b) (c) (d)

Figure. 8 Macrographs of showing microstructure of heated Sample No. 3 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



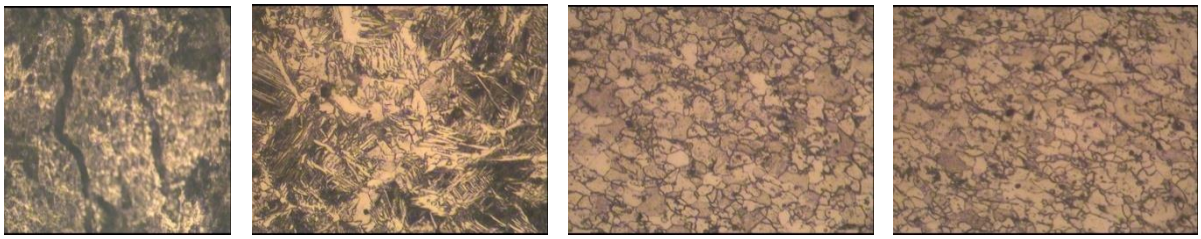
(a) (b (c) (d)

Figure. 9 Macrographs of showing microstructure of heated Sample No. 4 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre**.**



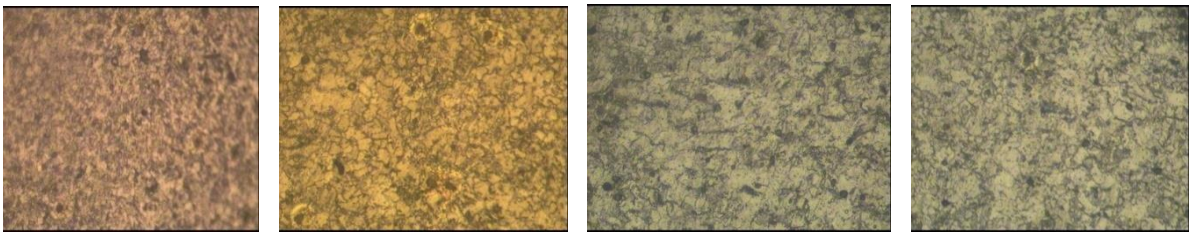
(a) (b) (c) (d)

Figure. 10 Macrographs of showing microstructure of heated Sample No. 5 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre**.**



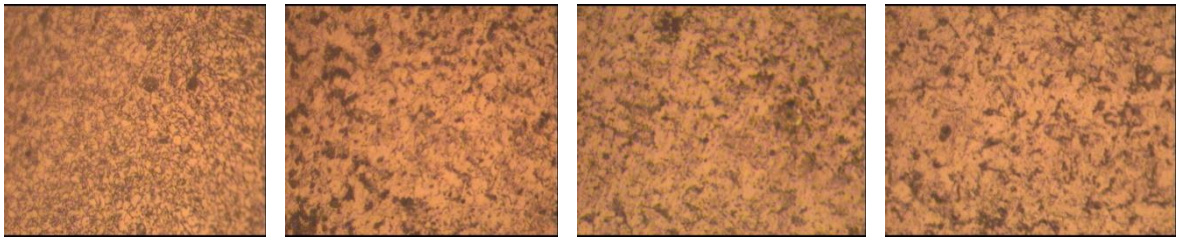
(a) (b) (c) (d)

Figure. 11 Macrographs of showing microstructure of heated Sample No. 6 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



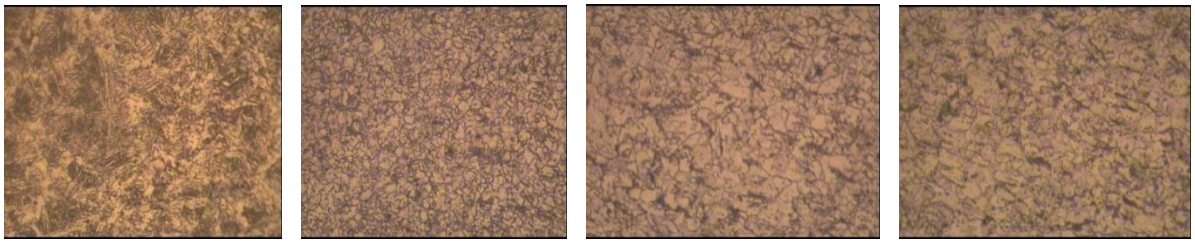
(a) (b) (c) (d)

Figure. 12 Macrographs of showing microstructure of heated Sample No. 7 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



(a) (b) (c) (d)

Figure. 13 Macrographs of showing microstructure of heated Sample No. 8 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.



(a) (b) (c) (d)

Figure. 14 Macrographs of showing microstructure of heated Sample No. 9 with 400X magnification at four different locations on the specimen: (a) At centre (b) 5mm from centre (c) 10mm from centre (d) 15mm from centre.

IV. CONCLUSION

The intrinsic mechanical differences between various samples are evident. The graphs show that the influence of the flame heating on the mechanical response and are in relation with the vickers hardness values of various samples. Grain growth occurs when holding the metal at recrystallisation temperature for an extended period of time, or at a higher temperature, allows the average grain size of the metal crystals to increase. This is because the grain boundaries have a higher energy than a perfect lattice, so there is a driving force to increase the grain size and thereby reduce the area of grain boundaries. Finer the grain size, lesser is the ductility because slip is

restricted. In case of larger grains, larger amounts of slip can occur thus giving better ductility. The Hall–Petch relation predicts that as the grain size decreases the yield strength increases. Microstructure analysis reveals reduction in the size of grains and reduction in the amount of pearlite improve the hardness at heat affected zones. During heating of IRS:M41 structural steel, an exceeding of oxy acetylene pressure, torch nozzle diameter and the holding time have detrimental effects on mechanical and microstructural properties. The relationship between the microstructural features, tensile & yield strength, elongation and vickers hardness of material at different combinations of the above parameters were analysed and results were correlated. Based on the experimental results, this study reveals that the consequences of flame straightening on microstructure and mechanical properties are influenced by oxy acetylene pressure, torch nozzle diameter and the holding time.

V. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the staff members in Strength of Materials Laboratory, PSG College of Technology, Coimbatore, Bharat Earth Movers Ltd., Palakkad, Kerala and Steel and Industrial Forgings Ltd, Thrissur, Kerala during various phases of experimentation and technical assistance for this work.

VI. REFERENCES

[1] D Schafer, V Rinaldi, D.Beg ,Optimization and improvement of the flame straightening process.RTD Info. European Commission Directorate-General for Research and Innovation (2012)

[2] Research Design and Standards Organisation (RDSO), Ministry of Railways. Specification for Corrosion Resistant Structural Steel used for Rolling Stock Serial No. IRS-M41, (1997).

[3] Bharat earth Movers Limited (BEML) Shell installation Drawing No. 929-40001

[4] R. Lacalle, Influence of Flame Straightening Process in Micro-structural, Mechanical and Fracture properties of S235 JR, S460 ML and S690 QL Structural Steel. Society for Experimental Mechanics, 53 : 893-909. (2013)

[5] Dean Deng, Numerical simulation of welding distortion in large structures. Computer Methods in Applied Mechanics and Engineering, 196: 4613-4627. (2007)

[6] K Sampath, An understanding of HSLA-65 Steels. Journal of Materials Engineering and Performance, 15: 32-40. (2006)

[7] O. Okman, Free forming of locally heated specimens .International Journal of Machine Tools and Manufacture; 47: 1197-1205. (2007)

[8] Yongjun Shi, Yancong Liu , Effect of different heating methods on deformation of metal plate under upsetting mechanism in laser forming. Journal of Optics & Laser Technology; 44 : 486-491. (2012).

[9] M.P. Lightfoot, N.A. McPherson , Artificial neural networks as an aid to steel plate distortion reduction. Journal of Materials Processing Technology,172,238-242, (2006)

[10] Bernd-Arno Behrens,Klaus-Georg Kosch, Characterizing the buckling behavior of cylindrical hollow and hybrid specimens by experimental upsetting tests. Prod.Eng.Res. Devel. 7:167-176. (2013)

[11] G.Yu, RJ Anderson),Efficient Simulation of shell forming by line heating. International Journal of Mechanical Sciences 43: 2349-2370.(2001)

[12] PK Ray, BB Verma and PK Mohanthy,Spot heating induced fatigue crack growth retardation. International Journal of Pressure Vessels and Piping 79: 373-376.(2002)

[13] M. Sunar, BS Yilbas,Thermal Stress analysis of a sheet metal in welding. Journal of Material Processing Technology 172 : 123-129.(2005).

[14] Dale H.Besterfield ,Total Quality Management, Pearson education,(2011).

[15] Indian Standard IS 1608:2005 Metallic Materials – Tensile Testing at Ambient Temperature,(2005).

[16] Indian Standard IS 1599 Method of bend test (Second Revision),(1997).

[17] Metallography and microstructures, ASM Handbook Vol-9.(2004).

[18] Research Design and Standards Organisation (RDSO), Ministry of Railways. Specification for Classification, Testing and Acceptance criteria of Manual Metal Arc Welding electrodes and gas welding rods, (2002).

[19] Railway Systems, Technologies, Operations across the world – Railway Technical Hand book,(2009).

[20] SAIL, Salem – User's Manual(2003).

[21] Ship Structure Committee -198,Flame Straightening and its effect on base metal properties.(1969).

[22] Frank Marlow. Welding Fabrication and repair, Industrial press, (2006).