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Augmentation of carburized mild steel weld properties to control chafing incidence

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Abstract

Structural failures which occur in construction sites have been a major engineering concern worldwide. In Nigeria for instance, most failures which have been investigated, have been found to occur at welded joints. Therefore, this study is aimed at augmenting the wear and mechanical properties of weld metals to reduce the incidence of chafing, so that they can accommodate expected design loads and last through the expected service life. Deposited weld metals were carburized with a mixture of coal and calcium carbonate and the carburized weld metal were further tempered to reduce the brittleness and relieve the internal stresses built in of the carburized weld metal induced by the excessive absorption of carbon into the carburized weld metal. Wear analysis was conducted to determine the extent to which the carburized mild steel could resist wear or scratch (chafing) and the wear properties were compared with those of the uncarburized mild steel welds. It was found that wear rate of the carburized and uncarburized mild steel welds are 1.83 x 10^{-5} cm^3/s and 5.94 x 10^{-5} cm^3/s respectively. From the mechanical tests conducted the carburized mild steel welds are 1.79 times harder than the uncarburized ones. Also the carburized mild steel welds are 1.51 times higher in strength than the uncarburized mild steel welds. It is therefore, concluded that carburizing the mild steel welds has certainly improved their wear and mechanical properties and significantly reduced chafing. This study elucidates a step by step approach.

Keywords: carburized mild steel welds, carbon, wear, mechanical properties, tempering

1. Introduction

Weld metals are known to have low strength when compared with their parent metal (Achebo, 2011). During the welding process, when weld metals are being formed, the intense heat which causes the melting of the electrodes to form the weld pool causes the weld metal to lose some of its carbon content upon cooling, by forming carbon monoxide which vaporizes as gas. The loss of carbon invariably reduces the weld hardness and strength. Investigators have invested a lot of effort in finding ways on how to improve the strength characteristics of weld metals in order to also improve the service life of both the weld metals and parent metals. Gupta (2009) improved on the mechanical and wear properties of mild steel samples by carbonizing them. Achebo (2011) in his work improved the strength of mild steel welds by altering the alloying elements that constitute the weldment. Boiniardi and Tagliabue (2006) improved the strength of steel gears by carbonizing and nitrating them. Chen et al (2008) improved the wear properties of a stellite 21 alloy by plasma surface alloying with carbon and nitrogen. Gupta (2009) reported that nitriding is a surface hardening heat treatment that introduces nitrogen into the surface of steel at a temperature range of 500 to $600^{O}C$ while it is still in their ferrite condition.

When welds strength properties are augmented, heavier loads with both normal and complex morphology could be accommodated. For example, in bridge design, vehicles of various weights and shapes are accommodated. The joints of the structures used for constructing the bridge must be strong and tough enough to carry the load for over a humdred years. The importance of this study in augmenting weld strength cannot be overemphasized.

In this study mild steel welds are carbonized to improve their wear (anti chafing) and mechanical properties, so that weld joints can attain almost the same service life as that of the parent metal and can sustain design loads to the expected service life.

2. Methodology

In this study, the methods utilized are as discussed hereunder

2.1. Pack carburization

Mild Steel welds are embedded into the powdry mixture of 90% Coal and 10% $CaCO_3$. The coal is obtained from Enugu State and Crushed with a hammer mill and the Crushed Coal was sieved using a Mechanical Siever. About 3.5kg of Powdery Coal was used for this investigation.

The mixture is heated in a confined container furnace to a temperature of between 850°C to 950°C in 2 hours. This temperature range as claimed by most researchers as the range at which carburization is expected to take place in low carbon steel welds. The hot air in the furnace, when it mixes with the carbon that is expelled from the coal, the reaction forms carbon monoxide. This is represented as follows:

$$2C + O_2 \rightarrow 2CO \quad (1)$$

The formed carbon monoxide surrounds the embedded mild Steel. The carbon content from the carbon monoxide diffuses into the Iron contained in the embedded steel. This is shown in the reaction expressed as follows:

$$Fe + 2CO \rightarrow FeC + CO_2 \quad (2)$$

The introduction of $CaCO_3$ would cause the addition of carbon diffusion into the Iron. This process would increase the hardenability of the mild steel and further increases its wear resistance by the following reaction:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (3)$$

$$C + CO_2 \rightarrow 2CO \quad (4)$$

From Eq (4), the reaction takes us back to Eq. (2) and after the carburization process, the weld samples were quenched in water.

2.2. Tempering

Tempering occurs after the hardening operation. The aim of tempering is to reduce the brittleness imparted by hardening, because carburised welds can be harder than is required and too brittle to be used for any Engineering purposes. This is because severe internal stresses have been built up during the rapid cooling from the hardening temperature. To relieve these internal stresses and reduce brittleness, tempering is carried out after the hardening (Carburization) process (Gupta, 2009).

2.2.1. Tempering procedure

The Solidified weld deposits are heated to a temperature below the carburizing or hardening temperature (200℃) in a furnace. The welds were kept for 30mins. After this time, they were cooled in still air. The resultant Strength often reflects ductility and high strength value.

2.3. Wear

Wear involves the loss of material from a parent material due to the chafing action inherent in metal movement impact. This is usually measured by determining the metal loss by weight. Wear resistance is measured by the loss in weight per unit area per unit time (Gupta, 2009).

2.3.1. Wear test

2.3.1.1. Grinding/polishing machine

An automated Polisher Econet II Cinder made from Buehler United Kingdom was used. It consists of an electric motor, a polishing/grinding rotating circular flat disc, rotating at 250 rpm is used for smoothening welds and steels samples used for hardness test and micro structural test. This machine was used for the wear test. A 460 grit emery cloth was placed on the rotating disc and the carburised weld samples were pressed on the rotating emery cloth for 5 mins by hand. The hand force is assumed to constitute about 18N. The weight losses obtained were taken as the measure of wear. This test for weight loss is expressed as shown in Eq (5)

$$W_1 - W_2 = W_3 \quad (5)$$

Where, W_1 = Weight of the carburized weld samples before the test.

W_2 = Weight of the carburized weld Samples after the test.

W_3 = Weight loss.

The weights of the Samples were measured with an electronic weighing machine.

The test was conducted 5 times and the average of the weight losses was taken as wear.

Other parameters were determined, Such as (Gupta, 2009):

2.3.2. Wear volume

$$\text{Wear volume} = \frac{\text{weight loss}}{\text{desnity}} \quad (6)$$

Density of weld specimen = 6.48 g/cm^3

2.3.3. Wear rate

Wear rate is defined as wear volume per unit distance travelled.

$$\text{Wear rate} = \frac{\text{wear volume}}{\text{sliding distance(sec)}} \quad (7)$$

$$\text{Sliding distance} = \left(\frac{2\pi RN}{60}\right) \text{x Time} \quad (8)$$

Where, R is the radius of the abrasive wheel = 5.5cm, N is 250rpm, time, t = 5mins = 300 seconds.

2.3.4. Wear Resistance

$$\text{Wear resistance} = \frac{1}{\text{wear rate}} \quad (9)$$

Table 1 shows the experimental results obtained from the determination of weight loss of the carburized mild steel welds.

Table 1
Wear properties of carburized mild steel welds

No	Sample A (g)			Sample B (g)			Sample C (g)			Sample D (g)			Sample E (g)		
of test	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3
1	605	599	6	582	576	6	642	638	4	514	509	5	619	614	5
2	610	606	4	616	612	4	644	638	6	618	612	6	582	576	6
3	590	584	6	618	614	4	620	613	7	532	529	3	670	662	8
4	587	580	7	610	605	5	590	588	2	562	558	4	593	588	5
5	598	592	6	594	588	6	632	528	4	581	577	4	586	581	5
			5.8			5.0			4.6			4.4			5.8

Table 2 shows the experimental results obtained from the determination of weight loss of the uncarburized mild steel welds.

Table 2
Wear properties of uncarburized mild steel welds

No	Sample A (g)			Sample B (g)			Sample C (g)			Sample D (g)			Sample E (g)		
of test	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3	W_1	W_2	W_3
1	580	556	24	710	698	12	616	602	14	582	568	14	616	605	11
2	612	582	30	524	512	12	428	410	18	572	557	15	635	615	20
3	623	609	14	620	608	12	510	495	15	698	676	22	728	709	19
4	586	571	15	581	567	14	608	589	19	674	652	22	610	586	24
5	605	589	16	526	516	10	648	629	19	614	602	12	520	507	13
			19.8			12			17			17			17.4

The wear of both the carburized and uncarburized mild steel welds were determined using Eq (10),

$$Wear = \frac{\sum_{i=1}^{n}\left(Ave.Weight\ loss\right)}{n} \quad (10)$$

Where n is the number of samples tested

2.4. Mechanical properties

The methods used for obtaining the mechanical properties were obtained from the works of Achebo (2008). These are discussed here under:

2.4.1. Brinell hardness test

An Avery Brinell hardness tester was used to carry out the hardness test. The machine consists of a hydraulic pump, which applies a load of 3000 kg. When the load is applied, it pulls down a plunger that contains a ball indenter made of tungsten carbide, of diameter 10mm on the weld specimen for 10 seconds. The weld specimen rests on a steel bed that is moved up and down by a hand wheel.

2.4.2. Tensile strength test

1. Tensile test specimens of dimensions shown in Fig. 1 were machined from the all-weld metal deposits.

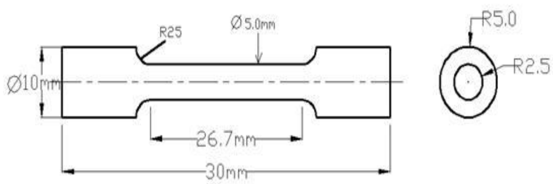

Fig. 1. Tensile strength test specimen.

2. Tensile tests were performed on the specimens using the Monsato Extensometer;

3 The tensile test parameters: yield strength, ultimate tensile strength, fracture strength, percent elongation and reduction in area were determined using the extensometer graph and dimensions of specimen before and after test using the following formulae

i. $$Engineering\ Stress,\ \sigma = \frac{Uniaxial\ tensile\ load}{Original\ Cross\ sectional\ Area} = \frac{F}{A} kg/mm^2 \quad (11)$$

ii. $$Engineering \quad Strain\ e = \frac{Change \quad in \quad length \quad of \quad Sample}{Original \quad length \quad of \quad Sample} = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0}. \qquad (12)$$

where l and l_o represent the final and original lengths of the tensile test specimen

2.4.3. Notch impact test

1. Impact test specimens of dimensions shown in Fig. 2 were prepared from
the all-weld metal deposits;

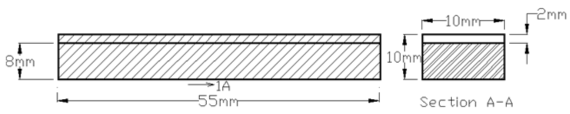

Fig. 2. Notch impact strength test specimen.

2. Impact tests were performed on the specimen using the Avery Dennnison Charpy-Izod Impact testing machine of a capacity of 0 – 150J on the scale;
3. The impact test results which indicate the energy absorbed as the specimen is fractured were read off the scale.

2.4.4. Hardness test

1. Test samples made from the all-weld metal deposits were machined using a lathe machine;
2. The machined samples were further smoothened using a 400-grit emery paper to produce mirror-like weld samples
3 The Avery Brinell hardness tester was used to make an impression or indentation on the smoothened samples for 10 seconds each.
4. The Avery pre-calibrated microscope was used to determine the diameters of the indented samples
5. Equation (13) was used to determine the Brinell hardness number (BHN) of the samples

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \qquad (13)$$

Where, D = diameter of the ball,10 mm
d = diameter of the impression, mm
P = applied load, 3000 kg

3. Discussion of results

In this study, mild steel welds were carburized by embedding weld deposits into a mixture of coal and $CaCO_3$. These elements are locally sourced. The mixture contains 90% coal and 10% $CaCO_3$ heated to a temperature of 900^0C. The diffused carbon into the weldments increased their hardenability and toughness. The carbonized mild steel welds were further tempered to reduce their brittleness and improve their ductility and wear resistance ability to resist scratching or abrasion (chafing). From the wear analysis alone using Eqs (6-10), it was found that the volume of wear is 0.79cm^3. The wear rate is 1.83 x 10^{-5} cm^3/s the wear resistance is 54644.8 s/cm^3. For the uncarburized mild steel welds, the wear analysis shows that the wear rate is 16.64g, wear volume is 2.57cm^3, wear rate is 5.94 x 10^{-5} cm$^3/_5$ and a wear resistance of 16,821.87 s/cm^3 was obtained. From these test results, there is a clear indication that the carburized weld samples possess strengths have been greatly augmented when compared with those of the uncarburized weld samples. The metal is now less prone to chafing.

Mechanical tests were carried out to confirm the indication of the results given by the wear test. The mechanical tests are the hardness test, toughness test and the tensile test. The results of these tests are tabulated in Tables 3 and 4.

Table 3
Mechanical test results of carburized mild steel welds

Sample	carburized mild steel weld		
	BHN	CVN, J	UTS, N/mm^2
Weld metal 1	345	95	532
Weld metal 2	282	105	575
Weld metal 3	382	120	670
Weld metal 4	375	145	720
Weld metal 5	310	175	480
	338.8	118	595.4

Table 4 shows the mechanical test results of uncarburized mild steel welds.

Table 4
Mechanical test results of uncarburized mild steel welds

Sample	uncarburized mild steel weld		
	BHN	CVN, J	UTS, N/mm^2
Weld metal 1	220	95	320
Weld metal 2	190	60	286
Weld metal 3	210	110	410
Weld metal 4	170	80	450
Weld metal 5	156	72	485
	189.2	83.4	390.2

From Tables 1 and 2, it is shown that the carburized mild steel welds are 1.79 times harder than the uncarburized mild steel welds. The carburized mild steel welds are 1.41 times tougher and can better absorb impact loads than uncarburized mild steel welds. The carburized mild steel welds are also 1.53 times higher in strength than the uncarburized mild steel welds with a reduced incidence of chafing.

From the analysis above, it can be deduced that the incidence of chafing, being the amount of wear, wear volume and wear rate of the carburized mild steel welds is less than that for the uncarburized mild steel welds, and, the wear resistance of the carburized mild steel welds is higher than that for the uncarburized mild steel welds. This shows that the loss of carbon in the heat affected zones (HAZ) which eventually became part of the weld metal microstructure affected the strength of the weld metal which in turn affected the load bearing capacity. The carburization of the weld metals augments the strength and load bearing capacity of the weld metal. This is evident in the results from the mechanical tests conducted, which showed significant improvements in the quality of the weld.

4. Conclusion

A study was carried out to improve the wear and mechanical properties of mild steel welds. Mild steel is a low carbon alloy steel with low strength. Therefore making a weld deposit of it would ordinarily result in losses of some of its carbon content, which further reduces the strength. In order to increase the strength of the weld and reduce the incidence of chafing, which would eventually increase its load bearing capacity, mild steel welds were augmented by being carburized and tempered. This treatment introduced carbon into the weld metal and also reduced its brittleness and made it more ductile and amenable to broad based engineering use. These desired strength characteristics have been achieved and are evident as shown in Tables 1, 2, 3, and 4. This study has clearly shown that carburization is a trusted method for improving weld metals strength.

References

Achebo, J. I., 2008. Development of Aluminium Welding Flux from Local Raw Materials. Ph.D. Thesis, Department of Production Engineering, University of Benin, Nigeria.

Achebo, J.I., 2011. Influence of alloying elements on HAZ toughness of multilayer welded steel joints. Int. Journal of Advances in Science and Technology, Vol. 3, No. 4. (In Press).

Boiniardi, M., Tagliabue, C., 2006. Influence of carburizing and nitriding on failures of gears – A case study. Engineering Failure Analysis, 13, pp. 312 - 339

Chen, J., Bell, T., Dong, H., 2008. Improving the wear properties of stellite 21 alloy by plasma surface alloying with carbon and nitrogen. Wear, 264, pp. 157 – 165.

Gupta, J., 2009. Mechanical and Wear Properties of Carburized Mild Steel Samples. M.T. Thesis, Department of Mechanical Engineering, National Institute of Technology, Rour kela.