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Application of Flux Cored Arc Welding (Fcaw) with Buttering for Heavy Structures in Ship Building Fabrication & Construction of Heavy Offshore Structural Steels

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Application of Flux Cored Arc Welding (Fcaw) with Buttering for Heavy Structures in Ship Building Fabrication & Construction of Heavy Offshore Structural Steels

ABSTRACT

In afloat repairs of the ships, offshore oil and gas installations and utilising the YRBM (yard repair berthing and messing vessels) for afloat repairs of Naval vessels etc., it is often noticed that the designed lengths of the structural beams and profiles may not exactly fit at the location to the required dimensions. There may be some minor gaps that are frequently observed in such cases and it necessitates to build up the small piece of material and to do the proper welding in situ conditions. Another best method to improve the weld joint in the gap is the application of Buttering in the gaps. In other words, the addition of material, by welding, on one or both faces of a joint, prior to the preparation of the joint for final welding, for the purpose of providing a suitable transition weld deposit for the subsequent completion of the joint will be usually done in the above applications. This process is called as Buttering, and it is also applied when trying to join two materials that may not be compatible, then the welder deposits a layer of weld on one or both surfaces that then enables a metallurgically compatible weld to be performed. In fusion welding processes, during the construction and fabrication of heavy offshore structures, several failures have been noticed during the welding of structures with higher plate thicknesses where preheating is not properly done. In this context, experimental studies have been performed on transient heat transfer in welding distortion control by using flux-cored arc welding process (Self Shielded-SS) with pre-heating and as well as introduction of buttering in both preheating and without preheating conditions, as specified by the various welding international codes. The authors have studied various samples and tested in which the FCAW welding with preheat and application of buttering happens simultaneously. The use of tubular electrodes with very small diameters has extended the use of this process to work pieces of smaller section size. A main advantage of using flux-cored arc welding (SS) is the ease with which specific weld-metal things can be developed. By adding alloying elements to the flux core, virtually any alloy composition can be produced. The process is easy to automate and is readily adaptable to flexible manufacturing systems and robotics.

Keywords: Flux Cored Arc Welding **(**FCAW), buttering, tubular consumable electrodes, porosity, dual shield welding, wire feed speed, arc voltage, travel speed and travel angle, Welding Procedure Specification (WPS), Procedure Qualification Record (PQR), Self-Shielded (SS), mild and low alloy steels, nickel alloys, bias and hoop members, solid node

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Introduction

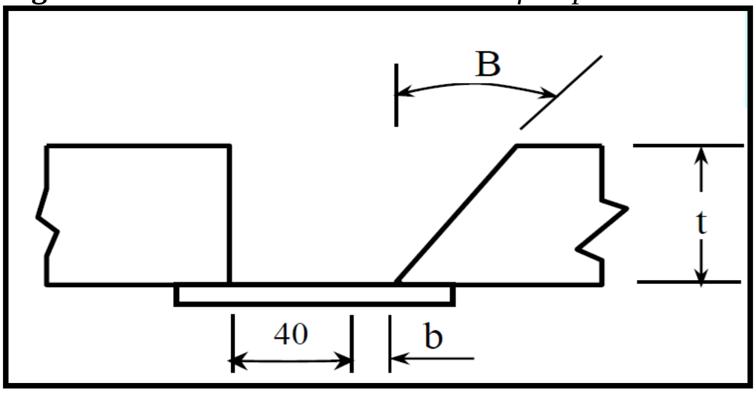
"Buttering" is a term used for adding weld metal to build a part up. if a machine a cast part and there is not enough cast to allow for machine clean-up then the process that would be used is to "butter it up" to get complete clean-up. Definition of buttering from BSEN ISO 15609-1 (WPS) and BSEN ISO 15614-1 (PQR).

Buttering: the addition of material, by welding, on one or both faces of a joint, prior to the preparation of the joint for final welding, for the purpose of providing a suitable transition weld deposit for the subsequent completion of the joint. Buttering is when trying to join two materials that may not be compatible, then the welder deposits a layer of weld on one or both surfaces that then enables a metallurgically compatible weld to be performed. Similarly, in welding also the buttering is an application of a process where there is a need to weld complete penetration butt weld between two materials thickness range from 50mm to 200mm. During installation of structures, the linear dimension is not meeting the drawings dimensions and not meeting the structural steel tolerances in total length, then process with buttering by welding either by deposit weld layer on the one side of the base materials to continue to fill the gap to meet the overall length as per drawings. See details in the joint sketch Figure 1. In other words, buttering is simply a weld build-up of (one or both) base metal(s) before beginning to weld the joint itself. This can be done in order to make up for poor joint preparation as indicated previously.

Research Work Done

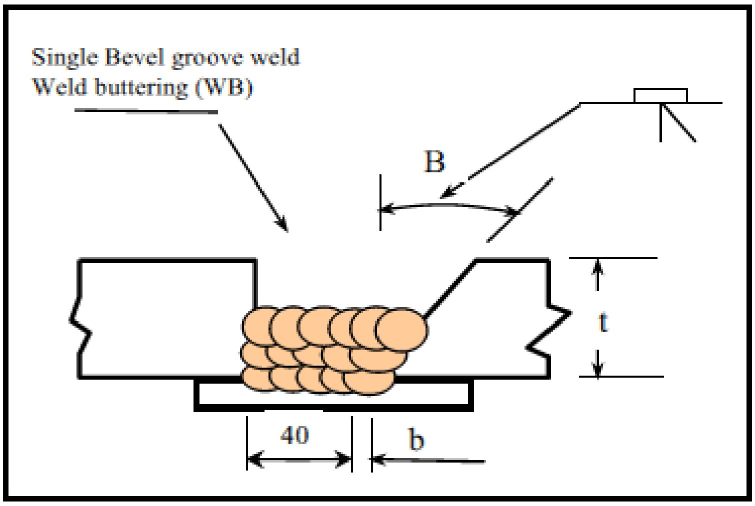
The authors have studied the requirement of preheating in the Flux Core Arc Welding (FCAW) Process and its advantages and disadvantages with preheating while applying the buttering technique in the welding to fill the major gaps in joints. After conducting number of experiments with various weld joints in the marine hull fabrication & construction industry and also studied the suitability of the application of preheating requirements as per rules and its real implications in the actual weld joint strength. The pictures below (Figure 1) show the dimensional gap between the two beams where buttering is to be done.

Figure 1. *The Dimensional Indication of Gap between Two Joints*



In addition to this, the difficulties in joining of dissimilar metals are to compose different properties of metals in order to minimize material costs and at the same time to maximize the performance of the equipment and machinery. There are a lot of methods of joining of metals. However, the fusion welding is mostly used in a wide range of industries. This research is carried out for the process of dissimilar welding between carbon steel plates of BS EN 10025-2: S355 to S460 and S460 to S460. The pictures below (Figure 2) show the buttering done with the application of FCAW-SS.

Figure 2. *The Buttering Welding with FCAW done to Fill the Gap between Two Joints*



Welding design used is a single bevel with wide gap by using the buttering process. Types of filler metals used are E71T-8. The weldment is then tested by non-destructive test (NDT) and destructive test (DT). Weldment is also characterized by using Ultrasonic Examination (UT). The results show that the mechanical properties of weldment with buttering process are better compared with the weldment with a non-buttering process. The macro and microstructure of weldment with buttering process revealed finer grained and homogeneous structures compared with the one by using a non-buttering process.

Preheat Requirement

Practically, there will be several problems associated with the butter while doing the welding by the Flux Core Arc Welding (FCAW) process. One of the serious practical problem is, if it is needed to weld heavier sections pre-heat shall be maintain the minimum temperature of 75℃ based on experimental studies in accordance with BSEN 1011-2, based on CEV refer fig.C2a to C2m.

Difficulties in Preheating

In welding of large structures such as aircraft, automobile, and military vehicle body segments, bridges, ships, etc., in their in-situ welding applications, some of these structures, such as ships, buildings, and bridges are welded on site, and they cannot be moved. Others, such as aircraft, automobile, and military vehicle body segments, while they can be moved from place to place, they are typically too big for the commercially available ovens. The best that can be done with these large structures is to preheat, control the inter pass temperature, or torch (flame) heating, with temperature control conveniently done via temperature indicating crayons or infrared (IR) guns (pyrometers). Due to the difficulty of controlling local heating, it is best that forgiving steels be selected for applications involving large structures. By forgiving steels it is meant steels known to have low or no susceptibility to hydrogen embrittlement, such as low carbon steels (e.g., S355 or S460), stock sizes should be based on the strength of the selected steel relative to the loads that will be encountered in service. It is also wise to use weld metals (fillers) with significantly higher strength than that of the HAZ in the base steels. More importantly, the sequence of welding the various joints should be optimized to reduce constraint, hence the level of residual stresses.

In order to propose a best of way of welding these large structures in-situ, the author has studied the process of welding by FCAW with preheating. Various samples of these materials have been chosen and welding the samples have been done with preheating. They have been sent for testing in laboratories for the assessment of their strength. After which, a step by step procedure has been enunciated to follow for the application of FCAW with preheat and which is in contrary to the BS Code mentioned above.

Experimental Setup

The experiment is being done with Flux Core Arc Welding for typical heavy structures of plate thicknesses 25mm & 100mm. Here, in this paper, plate thicknesses of 25mm & 100mm have been taken as samples and welding was done with (25mm/100mm thickness) and preheat requirement. The data collected from various tests have been compiled. In this paper, only the test result of one sample is shown for explanation and demonstration as per BS

EN1011-2. A sample test procedure qualification test coupon is shown in Figure 3.

Figure 3. *Flux Cored Arc Welding Process (SS) – 2G Position*

Materials Tested

In addition to the above, different steel plates of thickness 25mm and 100mm material according to the BS EN 10025-2 Grade S355 & S460. S355 is a non-alloy European standard (EN 10025-2) structural steel, most commonly used after S235 where more strength is needed. It got great weldability and machinability. S355/S460 is named based on its minimum yield strength of 355/460 MPa (N/mm^2), However the yield strength reduces when we go up in thickness above 16 mm for flat products & hollow sections.

The test welds were prepared, welded, and tested in accordance with the requirements of British Standard document - BS EN 15614-1, on these materials. All the specifications and qualification of welding procedures and welding procedure tests have been strictly followed to assess the Yield Strength based on various thicknesses of the materials. It is an essential requirement when welding materials of specific steel groups that the appropriate preheat level shall be used in accordance with the requirements of EN 1011. Permitted hardness values given in the standard may be exceeded if the appropriate preheat temperature is not applied. Table 1 indicates the reduction in yield strength based on thickness.

Table 1. *Thickness vs. Yield Strength*

Thickness	Gr. S355	Gr. S460
Up to 16 mm	355 Mpa	460 Mpa
16 mm < t ≤ 40 mm	345 Mpa	440 Mpa
40 mm < t ≤ 63 mm	335 Mpa	420 Mpa
63 mm < t ≤ 80 mm	325 Mpa	410 Mpa
80 mm < t ≤ 100 mm	315 Mpa	390 Mpa
100 mm <t ≤ 150 mm	295 Mpa	390 Mpa

The welding details of process used in welding, current setup, voltage setup and size of the filler metal etc., are shown in the Table 2.

Table 2. *Welding Details on the Sample Tested*

Run	Welding Process	Size of filler Metal-mm	Current Amp	Voltage
114 (FCAW-SS)- Buttering				
Root	114(FCAW-IS)	2.0 Ø	200-300	20-27
Fill	114(FCAW-IS)	2.0 Ø	200-300	20-27
Cap	114(FCAW-IS)	2.0 Ø	200-300	20-27
114 (FCAW-SS)- Groove Weld				
Root	114(FCAW-IS)	2.0 Ø	200-300	20-27
Fill	114(FCAW-IS)	2.0 Ø	200-300	20-27
Cap	114(FCAW-IS)	2.0 Ø	200-300	20-27

The Parent Material Specification is BS EN 10025 to BS EN 10025 S460M to S460M (Group 2 - 2.1 to Group 2 - 2.1).

Code and Standard used is: BS EN ISO 15609-1:2004 for WPS and BS EN ISO 15614-1 for PQR
Material Thickness: 100mm
Weld Thickness: 100 mm

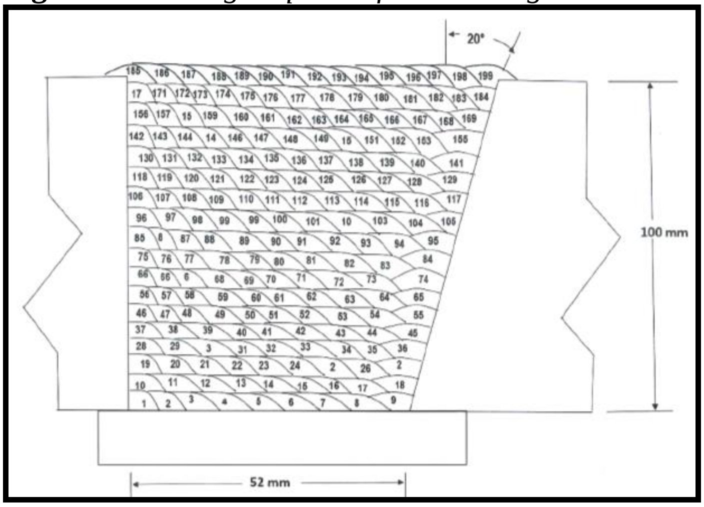
Concluded that for plate thickness 100mm welding was carried out with pre-heat and proven all the mechanical test results are meeting the code.

The welding procedure with the above-mentioned BS EN 15609-1 code requires a preheating to be done more than 20mm thick plates even after buttering proven subjected to closely monitor the parameters and by testing non-destructive and destructive. There is not much difference when compared to normal groove welds (without buttering). The samples have been tested in the laboratory for their tensile test, yield load and yield stress values. Reduced section transverse weld tensile tests have been conducted on these specimens. The specimens are named as T1(A), T1(B), T1(C), T2(A), T2(B), T2(C) where one full thickness tensile specimen divided into multiple tensile specimens: (A) – top, (B) – Middle and (C) Bottom. 100 mm thickness. The rise in temperature for preheating the materials does not change the material physical and chemical properties significantly, whereas the testing has been done to see if there are any changes in the mechanical properties such as strength, stiffness, toughness and hardness of weld joints with buttering. However, author conforms that even after buttering proven subjected to closely monitor the parameters and by testing non-destructive and destructive. There is not much difference when compared to normal groove welds (without buttering).

Overall Methodology

FCAW may be considered as an all position welding process. No shielding gas is needed for some wires suitable in windy conditions. Less cleaning of metal is required. Porosity chances are very low. Welding in this process has a high deposition rate. However, when it is applied in the industrial locations such as the heavy ship building and offshore structures, some precautions shall be taken scrupulously. They are (i) slag must be removed regularly, (ii) more smoke comes out as compared to other processes like GMAW and SAW, (iii) Spatter is more, (iv) wire is more expensive, (v) equipment is expensive and complex and sometimes site specific and Taylor made for a particularly application. The welding sequence used for Buttering is shown in Figure 4.

Figure 4. *Welding Sequence for Buttering with FCAW*



The experiment has been repeated for different welding positions such 2G (PC) position, 3G (PF) position etc. Every machine and consumables are of Taylor made. The welding process adopted is also a unique as explained in the section 2 of this technical paper. During this experiment one full thickness tensile specimen has been welded and divided into multiple tensile specimens: (A) – Top, (B) – Middle and (C) – Bottom. 0.2% proof stress and elongation value were obtained solely for reference purposes. Required Ultimate Tensile Stress for each weld joint shall be 550-720 N/mm^2. The Chemical compositions of the steels used in the welding procedure tests are shown in Table 3.

Table 3. *Chemical Compositions of S355/S460 Steels were used in Welding Procedures Tests Adopted*

Designation	C %	Si %	Mn %	P %	S %	N %	Cu %
S355JR	0.24	0.55	1.6	0.035	0.035	0.012	0.55
S355J0	**0.2**	**0.55**	**1.6**	**0.030**	**0.030**	**0.012**	**0.55**
S460JO	**0.23**	**0.60**	**1.8**	**0.040**	**0.040**	**0.027**	**0.60**
S355J2	0.2	0.55	1.6	0.025	0.025	-	0.55
S355K2	0.2	0.55	1.6	0.025	0.025	-	0.55

Identification of Welding Sequence for FCAW with Preheating

Following weld sequence (reduce the weld shrinkages) shall be implemented during welding on member thickness of more than 20mm thickness on the flange and web of heavy structural members. If we adopt the following welding techniques and welding procedures then we can avoid the failures due to temperature stresses in the buttering weld joints.

1. Fit-up shall be as per proposed experimental procedure shown in Figure 1, pre-heat joints as per welding procedure this will reduce effective shrinkage force.
2. Welder start welding of the joint from root run and subsequent passes as per macro sketch shown.
3. Continue the welding simultaneously until it reaches ¾ thicknesses of the member and stop welding for cool down.
4. Once the inter pass temperature reaches 250°c, the welders can stop the remaining welding until it reaches minimum pre-heat temperature.
5. Welder continues to weld to maintain the pre-heat temperature and inter-pass temperature until complete the weld.
6. Temporary attachments during the fit-up shall be kept until completes the weld and attain the room temperature.

Before Welding

1. Identify of parent material and Suitable welding consumable.
2. Deploy Qualified welder and welding operator.
3. To check Joint preparation and Fit-up.
4. Remove the painting & grind smoothly on bevel area.
5. No gap between backing plate and member surface.
6. No tack weld permitted on weld face.
7. Free from contamination.
8. Proper shelter to be provided for rain protection.
9. Helpers should be standing by.

During Welding

1 Preheat to be done for 150° C minimum by heating torch.
2 Interim pass temperature to be maintained between 150°C to 250°C.
3 After the completion of 50% weldment, joint should be covered with fire blanket to avoid sudden cooling.
4 Welding parameters to maintain.
5 Multi-layer welding only.
6 Welding sequence and control welding distortion.
7 Cleaning of runs and layers of weld metal.

After Welding

1. Perform visual inspection.
2. Conduct NDT (UT/MT).

3. Conduct destructive test (Mechanical test, Chemical & Macro).
4. Ensure dimension (shape, size & tolerances).
5. Report the documentation.

Results and Discussion

The results obtained after testing the mechanical properties of the materials when done on the samples with the application of buttering on the gap filling and, in the application, of FCAW with preheating are as shown in Table 4.

Table 4. *Mechanical Properties of Welding done in FCAW with Preheat (100mm Thick Plate)*

Specimen	T1 (A)	T1 (B)	T1 (C)	T2 (A)	T2 (A)	T2 (B)	T2 (C)
Tensile Stress	618	648	642	524	656	634	620
Elongation	17%	20%	26%	22%	33%	22%	23%

Flux Core Arc Welding with Self Shielding process with preheating applied on the test specimens and after subsequent testing as per standards has yielded strengths. The results obtained after testing the mechanical properties of the materials when done with FCAW **with buttering** is as shown in Table 5.

Table 5. *Mechanical Properties of Welding done in FCAW without Preheat (100mm Plate)*

Specimen	T1 (A)	T1 (B)	T1(C)	T2 (A)	T2 (B)	T2 (C)
Ultimate Tensile Load	637	640	645	662	638	620
Tensile Stress	577	592	548	656	634	638
Yield Stress	23	18	28	547	544	554
Elongation %	23	18	28	33	22	23

The weld pieces finished and tested for their mechanical properties are shown in Figure 5 and Figure 6 shows the welding being in the methods described above.

Figure 5. *Test Coupon in 2G & 3G Welding with FCAW*

Figure 6. *Welding 3G Position for Heavy Thick Plates*

Conclusions

FCAW-SS process for buttering with preheating is the most preferred welding process that can be easily adopted in ship building industry as this saves huge labour cost. Also, it is frequently used in construction industries for welding.

Buttering is also applied when welders are trying to join two materials that may not be compatible you deposit a layer of weld on one or both surfaces that then enables a metallurgically compatible weld to be performed.

Flux Core Arc Welding (FCAW-SS) is an arc welding process that using continuous flux-cored filler wire. The flux is used as a welding protection from the atmosphere environment.

For all experiments, the welding currents were chosen are 228A to 335A and the arc voltage is 21 V to 26 V respectively. 87 to 208 mm/min were chosen for the welding speed. The effect will be studied and measured on the penetration, microstructure and hardness for all specimens after FCAW process. From the study, the result shown increasing welding current will influence the value depth of penetration increased. Other than that, the factors that can influence the value of depth of penetration are arc voltage and welding speed.

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