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The Materials and Welding Associated with the Construction of SSK Submarine Hulls

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ABSTRACT

The construction of SSK Upholder class submarines is an important issue for the Canadian Navy now that the four vessels are to be transferred, beginning in the year 2000, from the United Kingdom to Canada. This is because an understanding of the fabrication methods will generate confidence in the integrity of the hull envelope and will directly assist the Canadian Navy when it becomes necessary to carry out future repair and refits. This paper describes the materials and methods of construction used in the fabrication of the hull envelope by people who were involved in the qualification of the weld procedures and one who was directly involved in the construction of this class of submarine. The paper records a number of new developments in welding, related to construction issues, which may have a role to play in future submarine maintenance.

Introduction

The transfer of the four Upholder Class Submarine from the UK to Canada from early 2000 onwards will undoubtedly lead to questions being raised as to the materials and methods of construction. This is particularly relevant with regard to service performance, refit and repair requirements. Initially what will actually be transferred should be known in some detail to the Canadian Navy and also the condition of these structures. The latter requirement may still necessitate hull structural survey in order to identify the initial condition on which future action can be based. This is because the submarine may have been worked up to operational condition for transfer but a complete condition report may not be available which details the overall condition resulting from the vessels being laid up over the past 10 years. Consequently some work, by the Canadians, maybe required before the first major refit to address any short comings resulting from the period of, extended, lay up.

This paper details the materials, consumables and welding procedures used in the construction of the Upholder Class submarines. The objective is to inform the Canadian authorities of these details so that they will be in possession of the appropriate knowledge should early maintenance of the hull envelope be required. The paper only deals with the materials and construction of the hull envelope and not the materials for systems, propulsor etc.

It should be noted that the Upholder class of submarines were built by the VSEL consortium at Barrow in Furness and Cammell Lairds, Birkenhead. SSK 01, Upholder was built at Barrow in Furness and SSK 02, Unseen, 03 Ursula and 04 Unicorn, being built at Birkenhead.

Steel

The early classes of submarine fabricated by the Royal Navy were constructed using riveted mild steel. The first use of welding in construction was employed in welding the ballast tanks of the A class around 1938. The first fully welded vessels were the T Class, beginning in 1942, starting with HMS Tiptoe, using 'S' grade steel. The O & P Class, of which four were supplied to Canada, employed QT28 in the construction of the hull envelope and UXW steel to fabricate the Tee frames. It was during the construction of these vessels that lamellar tearing was first encountered but its true significance was not fully recognised at the time. This had to wait until the construction of the UK nuclear submarine, HMS Dreadnought, which was fabricated from QT 35, a somewhat higher strength hull steel. (1).

More recent submarine construction in the UK first used HY80 steel followed by Q1N, the British version of HY80 steel. Table 1. It is the latter steel that was used to fabricate the Upholder class submarines and indeed, for the Trident Submarine build programme recently completed by the Barrow shipyard. This steel has been manufactured either using the basic electric arc melting or the basic oxygen steel making process followed, in both cases, by vacuum arc degassing. The composition of Q1N is similar to HY80 but at the time of initial manufacture was lower in the impurities Sulphur and Phosphorous. The steel used aluminium deoxidation practice and aluminium grain refining before the liquid Q1N steel was bottom poured in to 20 ton ingots. The as cast ingots were subsequently rolled, with a degree of cross rolling into the requisite plate thickness followed by quenching and tempering to attain the necessary 0.2% proof strength level. All plates were solution treated at 920°C, one hour per inch of thickness followed by water quenching in platen or roller quenching facilities. Tempering was carried out at between 625°C to 650°C for the requisite time depending on plate thickness, in order to achieve the specified 0.2% proof strength level. Table 2. The latest production of Q1N plate involves the direct rolling of Q1N ingot to the requisite plate thickness.

The use of low sulphur steel, basic electric furnace refining, aluminium deoxidisation, Aluminium grain refining and vacuum degassing ensured that the Manganese Sulphide, Manganese Silicate and alumino-silicate laminations, the cause of lamellar tearing in the QT35 were eliminated. The current supply of Q1N is free of these defects and so the steel has excellent through thickness properties. In order to maintain this quality all plates are subject to a through thickness NDE examination using an ultra sonic pulsed echo technique on a six inch square grid pattern. All plate not meeting the necessary requirements is rejected.

Mechanical Testing

The Q1N material specifications NES 736 Part 1- Plate; Part 2 - Forgings; Part 3 - Castings and NES 769 –Welding Consumables for Structural Steel. Approval System, and NES 770 Welding and Fabrication of Q1N steel, require that all materials used in submarine construction meet certain minimum standards. Tensile tests are used to determine 0.2% proof strength, charpy, and dynamic CTOD for toughness with bulge explosion tests for crack initiation and arrest properties. The latter is covered using plain or crack starter bulge explosion, flawed bulge explosion or hull toughness element tests. For the Upholder class, only two test methods were employed, namely the plain and crack starter bulge or the flawed bulge explosion tests..

The Q1N plate would have been qualified prior to its use in Upholder but the weld metal Table 3. would have been qualified depending on the weld procedures used either as a result of previous similar construction and/or specifically for the fabrication of the Upholder class. The test panels used to qualify weld metals and procedures are shown in Figure 1, incorporating the specific joint preparation, welding consumable(s), welding process and relevant welding parameters. Following radiography and ultrasonic examinations to confirm weld integrity the various weld property material tests would have been carried out to validate the welding consumable etc., before it was allowed to be used in construction. Table 4. There would have been close control of the welder, welding the weld procedure tests panels, who would have been monitored by a team of experienced welding inspectors to ensure the weld joint was completed as per the procedure.

It was not usual practice to employ weld run off plates in order to monitor weld properties during construction but in many instances weld property checks were made on cut outs removed from the hull. These samples were taken where access was required for penetrations and welds contained in that particular cut out piece would have been tested. Tests on material from these sources provided confirmation that the weld metal properties developed in the procedures were being achieved in the submarine hull welds.

Welding Consumables used in SSK Construction.

Whilst the Fortrex 11018 SMA electrodes were used on at least SSK001 and 002 Units there was a gradual change to the improved Fortrex NQ1 SMA electrode. Table 3. In each case it was imperative that the start area of each electrode run was gouged/ground free of possible porosity defects, this applied to the use of all SMA electrodes on structural steel throughout the build. Close control of run out lengths was maintained with QC Inspectors checking individual welders to ensure they were compliant with the laid down welding procedures thus maintaining the specified heat input requirements in order to develop the required mechanical properties. Table 4.

So as to minimise the possibility of hydrogen pick up in the weldment and thus the run the risk of encountering Hydrogen induced cold cracking in the HAZ, all SMA electrodes were baked at 400°C for 4 hours and then stored at 150°C until required for welding. VSEL practice was to issue the electrodes in plain quivers with silica gel granules placed in the cap, which must remain closed at all times, after taking out an electrode for the purpose of welding. Some companies use heated quivers set at a validated temperature to minimise the risk of moisture pickup from the atmosphere. Without proper control of electrodes moisture pick up can be significant depending on the atmospheric conditions of temperature and relative humidity. (2).

During earlier construction arc blow problems had been experienced with DC rectifiers in the shipyard, thus all SMA structural welds were carried out using AC power sources . Multi-operator main transformers were located in the shop and berth area from which numerous single reactance units were taken and placed in banks to allow welders easy access for connections via welding cables extending up to 50 metres from these units. Earthing needed to be strictly checked to ensure very good connections to sub units and the submarine on the berth if variations in current during were to be avoided.

Development work for the Trident project had involved the development of a 1.2mm diameter hybrid flux cored wire (FCAW), Dualshield 101TM, which met all the welding criteria, for welding Q1N steel, for use in nuclear submarine construction. Coupled with the technical merits of the consumable it soon became evident that substantial increases in productivity could be, and were achieved over existing SMA welding practices. The wire was all-positional and gained immediate acceptance for almost 80% of welding carried out during the construction of Trident. Concern was raised about the levels of weld metal hydrogen that could possibly be achieved using this wire in restrained butt welds. Shop floor tests (3) using a 'Yanaco' weld metal hydrogen analyser revealed minimal pick-up, even when taken over several days. In any case, the wire reels not used completely during the working day were stored in temperature controlled ovens set at 60°C. All reels were dated on release from the stores and controlled throughout their use.

For submerged arc welding the wire type used was a bare solid wire, Table 3. selected to ensure there was no hydrogen pick-up from wire drawing compounds that were sometimes found under coppered wire products. Care was taken to keep the wire free of rust and grease that could be picked up in the working environment. It was essential that the flux was kept dry and to this end it was mandatory that it should be baked at 400°C for 4 hours and kept at 150°C until ready to be used in the construction of decking or hull butt welds.

In order to maximise efficiency in the use of submerged arc welding flux, used and new flux was mixed but regulated to ensure there was not an excess of fine granules in the flux. It had been found that an excess of fine granules tended to mask the molten pool and hinder the release of gases, in extreme cases this it has been known to create large gas pores in the weld metal. All welding products were purchased from approved welding suppliers and batch test certificates were obtained for every individual batch of electrodes, wires and flux used to ensure the products were up to the standards and the mechanical properties stated in MOD specifications.

During fabrication QC Inspectors were tasked to obtain samples of both electrodes and flux from the shop floor and deliver them to the Chemist's department for moisture assessment. Moisture levels were assessed using the Gayley Woodings system, results being reported within hours of receiving the sample. Electrodes were sent in sealed copper tubes and the flux in sealed small chemistry bottles. Both were labelled and sent with a card recording where and when the sample was collected.

Construction

During the construction of the various vessels of this class of submarine there were several welding consumables and processes used on the same welded joints do to the vessels being built at the two shipyards belonging to the then VSEL Consortium. The aim of this paper is to relate the build of SSK with the MOD approved processes and consumables without detailing to specific hull seams and butt welds.

The Tee frames used in Upholder class construction were either rolled Q1N or where applicable extruded HY80. These tees would have been examined, shot blasted and primer painted before being bent to a set diameter using pinch rolls, a Hugh Smith Frame/Bulb Bar Radial

Bending Machine. Each T bar end would have been prepared for welding by gouging and grinding to the specified joint preparation. Using a simple jig and mandrel, the Tee sections were assembled with a set joint gap to form a full diameter ring, Figure 2: a glass or ceramic rod backing medium would then have been fixed on the one side and held down, before preheat was applied using strip electrical heating elements on either side of each joint. On attaining 70°C, the modified preheat temperature, the rings were first welded to the mandrel arms, in order to maintain the correct shape, using low hydrogen shielded metal arc electrodes, the first boats used the Murex Fortrex 11018 type or Murex NQ1type (E9016). Following the welding of the outer root gap, with 4.0mm diameter electrodes over the glass or ceramic rod, the welder was then able to complete the outer joint area using the 4.0mm diameter electrodes.

Once the first side web and table welds on all three connections had been completed, the preheat was stripped away to allow the rings to be turned over and the second side welded with preheat in operation after grinding back the root area of the weld to remove any defects which may have occurred. Full NDE inspection UT and RT was applied after a minimum of 24 hours waiting time, designed to allow for any entrapped weld metal hydrogen to escape. Any welding repairs would have been immediately undertaken and checked again to attain the required standard.

On completion of the Tee frame butt welds the rings were lifted onto a jig and set in position for a circumferential oxy-propane cutting machine, rotating from a fixed centre point, to cut the circumferential T frame web weld preparation. The machine cut the top and bottom edges of the weld preparation at the same time and a preheating torch was placed in front of the burning torches to preheat the plate, thus ensuring a good clean crack free cut. The cut surfaces thereafter only required a light grind to remove the surface oxide layer on the joint preparation and to correct the internal ring diameter dimension. This practice would essentially be the same for both rolled NQ1 and extruded HY80 tees. Following this operation the stiffener rings, axis vertical were placed on brackets set at the correct pitches on vertical steel channels to form the sub unit 'ribs' and fixed at the required pitch as per the submarine hull design. Figure 2.

The VSEL practice at this time was to use the stiffener rings to form a jig in order to construct the individual three frame hoops. This allowed the rolled plates to be positioned around the stiffening rings, which acted as a mandrel, being secured by means of numerous temporary attachments in the form of bolts and plates, the latter being welded to the hull plating, preheat being maintained at a genuine 70°C by hand held preheating gas (oxy propane) torches. Severe cracking problems can occur if insufficient preheat is undertaken on these highly stressed welds so the maintenance of accurate temperature control was essential.

The plate material, Q1N steel, used to form the hull envelope was procured to exacting specifications regarding quality and thickness. On arrival at Barrow all the plates were inspected by UT on a grid matrix to ensure that there were no laminations in the plates. Subsequently the plates were shot blasted and primed with Kharki Interplate NAA750/WAA001 weldable primer paint to a maximum DFT of 30 microns and given a unique plate number. All through the build sequence this unique number, for the specific plate, was marked on every subsection in order to identify from what and where each part of the plate was in the boat. Where necessary the hull plates would be either oxy-propane or plasma cut to size, before being transferred to a Hugh

Smith Edge Milling machine, for milling the double vee butt joint preparation on both ends of the plate. These preparations form the longitudinal seam joints which make up the individual sub units. With only one exception all the three plates that comprised one sub unit were prepared in this manner. The exception to this procedure was the closure weld where the final preparation was cut and gouged to fit. These plates were rolled to the required hull diameter on the Heausler German rolls. Formerly the ends of the plates had to be 'cracked' on one side and then turned over to complete the rolling operation. This cracking operation was to ensure that the sections were curved right up to the end and did not have a flat section. New equipment has now been installed which allows the steel plates to be rolled throughout the whole of their length without recourse to this action. After being checked by QC Inspectors the sections were then shipped to the main assembly hall for erection of sub units.

Before work was allowed to continue QC Inspectors checked the sub unit for the correct dimensional tolerances. Thereafter, electric strip heating was applied to the vertical seams and webs of each stiffener ring, all weld preparations were covered with a VSEL designed insulation tape to lessen heat loss and also reduce any burning risks to welders and platers working on the sub unit. Where possible and convenient, two vertical seams were welded at the same time, welding starting on the inside onto a glass rod backing pressed and held in the root of the outer joint which nominally was set to a 6 mm gap. Welding started in the central area of the seam, and completed to approximately a third of the seam length to lock the joint together. The top and bottom sections were filled alternately to form the skin of the hoop, Figure 2. and capped.

Whilst the joint design was made to eradicate air arc gouging, the production department used the latter process sparingly, in order to remove root defects before grinding the joint ready for the outer welding runs. Preheat was lowered or cut off during any grinding action. The method used on the inner weld was repeated on the outer preparation until the joint had been completed. The closing joint was cut and ground to make the required joint preparation and welded as per the previous seam welds.

The stiffener rings were welded to the hull using a Lincoln submerged arc Squirt welder. The equipment, connected to an arm, attached to a bearing disc, mounted in the centre of the mandrel, used 2.4mm diameter Oerlikon OES 3NiMo1 wire and basic OP41TT flux when depositing the weld metal.. The rings were welded in sequence and on finishing all the first sides, the sub-unit was turned over to enable the second sides to be welded, after applying a light grind to remove any defects in the root area. The preheat cables, disconnected for the turning of the units were reconnected and welding started once the specified minimum 70°C preheat had been reached in the area around the joints. Some of the joints at Cammell Lairds, the other sister company shipbuilder, were in fact welded using the newly developed Dualshield 101TM flux cored wire, since the relatively thin stiffeners were difficult to keep in tolerance with the submerged arc welding method. The rings on nuclear submarines were thicker and did not cause the same problems as the thinner webs on SSK. The use of FCAW significantly reduced distortion problems. Subsequently the use of temper beads was discontinued in this particular case, as it had been found that when attempting to attain the required weld reinforcement, the use of temper beads resulted in low uneven weld runs and poor shape. A blended shape was required to minimise stress raiser points in the toe areas, previously there had been considerable dressing by grinding required in order to attain the required standard.

The seams were fully inspected using Visual; MPI; RT and UT, but the full penetrating tee butt welds were examined by UT from the outside and Visual/MPI on the inner weld surfaces. All welds were examined after a minimum of 24 hours of the completion of the welding. QC inspections were once again undertaken to check the welded sub unit was within the design tolerances, any faults would need rectification work and subsequent re- NDE inspection.

In total twelve parallel-sided sub-units were produced, two of them (2.3 and 2.X) having HY80 extruded sections in place of one of the rolled Q1N tee stiffener rings. These two Tee frames were for the watertight bulkheads at frame 56 and 35 respectively, whilst sub –units 1.1, 1.2 and 1.3 were tapered units, requiring special skills to weld together correctly and in tolerance. The watertight bulkheads were made with Q1N steel, the long seams submerged arc welded and the connection to the extruded Tee frames made using the SMA process. The stiffener frames on the bulkhead itself were full penetration T-butt joints and were also welded using SMA electrodes. In principle all Tee frame welds in the construction of the submarine were full penetration welds.

The two dome end bulkheads were made and formed at Motherwell Bridge using the Fortrex 11018 electrodes to weld the preformed petals together. This is contrary to the way the O&P class domes were manufactured which was by spinning.

In the next stage the welding together of the sub-units to form shop or partial outfit units was carried out, including the incorporation of the dome end bulkheads. At this time the stiffener rings still had the spider channels in place spreading out from a central ring and connected and welded around the ring tables. To make one shop or partial outfit units the smaller sub units were set up on supports, with their axis horizontal, immediately in front of the large submerged arc welding rotator. The final units usually comprised of three sub-units except for the central unit which had four. Once they had been positioned correctly a large steel mandrel was fed through and connected to the rotator and the individual spider rings, making all items secure. A cantilever holding the submerged arc machines was swung over and positioned to allow two butt welds to be made at the same time. Prior to this, electrical strip preheating elements had been wrapped around each butt joint on the outside, they were held down by cross clips, which in turned were bolted down to the hull capacitance discharge CD studs which had been studded all around the hull. These studs were 'surface attachments' and not circumferentially welded as per SMA arc welded studs. Insulation strip was also used in the same way as for the vertical seam welds. Due to lack of space inside the units manual shielded arc welding was carried out on the inner side first once preheat had attained the correct temperature.

It should be noted here that through experience VSEL had slowly over the years reduced the temperature from 120°C to 70°C without cracking problems. Other non- experienced fabricators would be advised to keep to the original higher temperatures, even though this causes potential distortion problems and increased worker discomfort. The welding of the inside preparation was split into four sections using four welders to attain a balanced back-step welding sequence, see sketch.

Preheat was adjusted to keep the temperature as low as specified, as conditions could get very hot in the roof area of the units. With the completion of the inside welds the outside preparation was arc air gouged and ground back to sound metal ready for MP inspection before submerged arc welding started. The outside joint was submerged arc welded using a single solid wire called OES3NiMo1 with a basic flux OP41TT. The welding parameters employed were 500 A, 29-30 V and 500 mm /min travel speed. Both inside and outside weld reinforcements were gouged and ground smooth and flushed to facilitate for full NDE.

The next stage was to weld the two dome end bulkheads to their respective hull units, the fore end to unit 3A and the aft end to sub unit 1.1 and then both to unit 1B The welding processes used were mainly SMA and eventually as building progressed to the later boats, with the new semi-automatic welding wire and shielding gas.

On completion of the main circumferential hull butt welds it was now possible to weld in No 1 and 2 decks and the major castings and tank structures. The torpedo tube castings presented the most difficult problem since close control over welding sequence was necessary there being a combination of four tubes and the weapons embarkation casting in close proximity in the upper fore end dome area. Welding of these items was carried out using manual metal arc electrodes with an asymmetrical joint preparation, welding commenced on the inside and the outer joint preparation was completed using air arc gouging and grinding. After MPI, the welder would complete the joint using SMA electrodes and once again both sides of the weld would be flushed to enable NDE to be carried out to the specifications laid down.

Unlike the nuclear submarine this class of boat was designed to have a ballast keel which was fabricated in parts and welded to the hull unit sections in the assembly shop using both the SMA and FCAW welding processes

Whilst the hull and associated components were being completed a further set of tradesmen were constructing the external fore-end structure complete with ballast tanks, chain and anchor lockers and the seats for the sonar. The weapons embarking flat was a 'winged ' like fabrication which enabled, when fitted, the torpedoes to be slid down into the submarine via the hatch opening. Likewise, the bridge fin was built up with the main component being the Q1N steel conning tower casting assembly welded as a separate item before becoming part of the bridge section.

The aft end external structure was linked around the shaft tube, rudder housings, port and starboard hydroplane stabilisers together with No 3 and 4 main ballast tanks. Endless QC checks were made throughout the build time until the units were shipped at planned intervals down to the berth.

At this time the berth was a sloped area extending down to the Walney Channel. Future submarines would be launched via the 25,000 tonne ship lift immediately outside the main Devonshire Dock Hall (DDH) building hall. In fact all the SSK submarines have used this facility over several years for inspections and repairs as considered necessary, and now the pre-delivery refurbishment before the Upholder class submarines are moved to Canada..

For the completion of the hull on the berth traditional methods of setting the units onto the berth blocks were employed and great care and skill was taken in aligning and positioning the second unit next to Unit 3 (external structure and pressure hull fore end). Once positioned the two units were held together by steel temporary attachments welded, using the SMA process, onto the outer hull walls. Preheat strip elements were wrapped round the circumferential butt joint area and connected to the power sources. On attaining the required preheat temperature levels welding was commenced on the inside using similar block welding sequences, with SMA electrodes as used in the assembly shop. A covered tower, with welding stations and ladders inside, was lowered by crane to cover the joint so as to protect both the materials and personnel from the elements of wind and rain. The outer joint preparation was arc air gouged to remove root defects in the joint and another team of welders welded in block sequences similar to the inner weld, after NDE had cleared the weld of unacceptable defects.. There were two major static hull butt welds at the berth connecting the three large prefabricated submarine modules together.

The last major welding tasks concerned the closure plate welds for the shipping opening and access opening, on the top side of the hull to the stern of the boat, behind the bridge. The curved section of plate with rolled tee frames welded into the relevant position was positioned accurately and held in place by temporary attachments. Preheat was applied via the electrical strip elements. The inner weld was completed using a strict weld procedure sequence devised to minimise distortion and out of tolerance in the connection to the pressure hull. Air arc gouging and grinding of the outer butt joint preparation was carried out and checked before welding was completed as per the weld procedure sequence instructions. An intricate next stage required the welder to weld in frame sections between the existing frames and those welded onto the closure plate. This work was more complicated for welded frame sections between castings and the frame stiffener rings. Space and ease of welding were very restricted (non-existent), but even so the welds were fully inspected to the high standards of hull weldments. All these welds were completed using SMA electrodes.

Future Welding Developments of Interest to SSK Maintenance.

The use of the flux cored wire has been a great success in the Trident build programme, once welders had been correctly trained and gained acceptance of its potential in shipbuilding. Its use would be of interest to major re-fits and closure plate welds, but smaller work would still require the use of SMA welding if the welder skills for FCAW were not generally available.

Many brackets and support hangars were welded into position by SMA welding, but now the use of drawn arc studs and hangar brackets are preferred for the submarine build programmes. Care is necessary in applying the studs correctly, especially to the hull, but modern equipment with electronic controls and pre-set welding programmes have eliminated most of the early problems. The speed of application, no need to preheat the weld area, hold considerable benefits during refit. In addition the risk of fires caused by stray arcing and welding sparks are reduced considerably, especially in confined spaces where machinery etc may still be in place.

VSEL and MOD have recently completed trials using pulsed MIG and FCAW welding processes to assess the use of duplex stainless steel welding consumables for use on submarine refit work. The results have been very encouraging, especially in the Hull Toughness Element test, which applies an uni-axial stress to a welded test panel by means of a controlled explosion. The results have been superior to any ferritic structural steel weld as no crack emanated from the explosive test. Concerns about corrosion between the steel and weld material and sea water need not be a problem since all the hull is coated with protective primer and hull paints. The main problem may be the slight increase in welder skills required to manipulate the austenitic wires and the cost, perhaps three times a low alloy steel wire. However austenitic consumable costs continue to fall as a result of a significant increase in the tonnage use and a continuing search by the manufactures for new markets for the product. Originally the tests were carried out to identify a product which did not require preheat (except perhaps below 0°C in Arctic conditions) and to this end the trial was very successful. The use of a manual metal arc electrode may be more useful in confined areas, but the attainment of the currently specified minimum charpy values of 50 Joules at –50°C for weld metal may be just too high for such a consumable. However because the material does not have ductile/brittle transition behaviour, being austenitic, it may be possible to relax the charpy impact requirement without increasing the risk of early crack initiation or rapid crack propagation in the material. On a practical measure the SMA consumable would undoubtedly be superior to low alloy steel welds under shock loading conditions. Further work is necessary on SMA electrodes to gain approval for use on Naval Submarines.

Another area of recent development has concerned the use of electron beam welding of marine components from wrought Q1N steel in place of Q1N castings. Very few companies are capable of producing castings to the required Q1N steel quality requirements and they have to be made to lower standards than the hull envelope structure. This has caused problems when cladding the internal bores with Monel or Inconel and when joining a casting to the hull. For example, pores, in castings, acceptable to the casting code, have been located by RT when inspecting the valve to hull joint and found to be outside the plate weld acceptance level. Valves made from wrought Q1N plate and EB welded together can be assembled quickly to higher standards and present no problems regarding cladding or welding into the hull of a submarine, because being wrought products they do not contain porosity defects.

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Table.1 Typical Submarine Steel Plate Compositions

Submarine Class	Steel Type	C	Mn	Si	S	P	Ni	Cr	Mo	V
A Class Amphion	S	0.21	0.80	0.35	0.06	0.06	-	-	-	-
P Class Porpoise	UXW	0.14	1.40	0.25	0.04	0.05	0.35	0.23	0.25	
O Class Oberon	QT28	0.15	1.15	0.08	0.03	0.022	0.40	0.25	0.26	
SSN01 Dreadnought	QT35	0.15	1.20	0.30	0.040	0.035	1.20	1.00	0.50	0.12
SSBN Resolution	HY80	0.14	0.32	0.25	0.004	0.011	3.20	1.60	0.45	0.01
SSK, SSN SSBN Upholder Trafalgar Trident	Q1N	0.13	0.26	0.29	0.005	0.012	2.85	1.40	0.45	0.01

Table. 2 Mechanical Property Requirements for Submarine Steels and Weld Metal

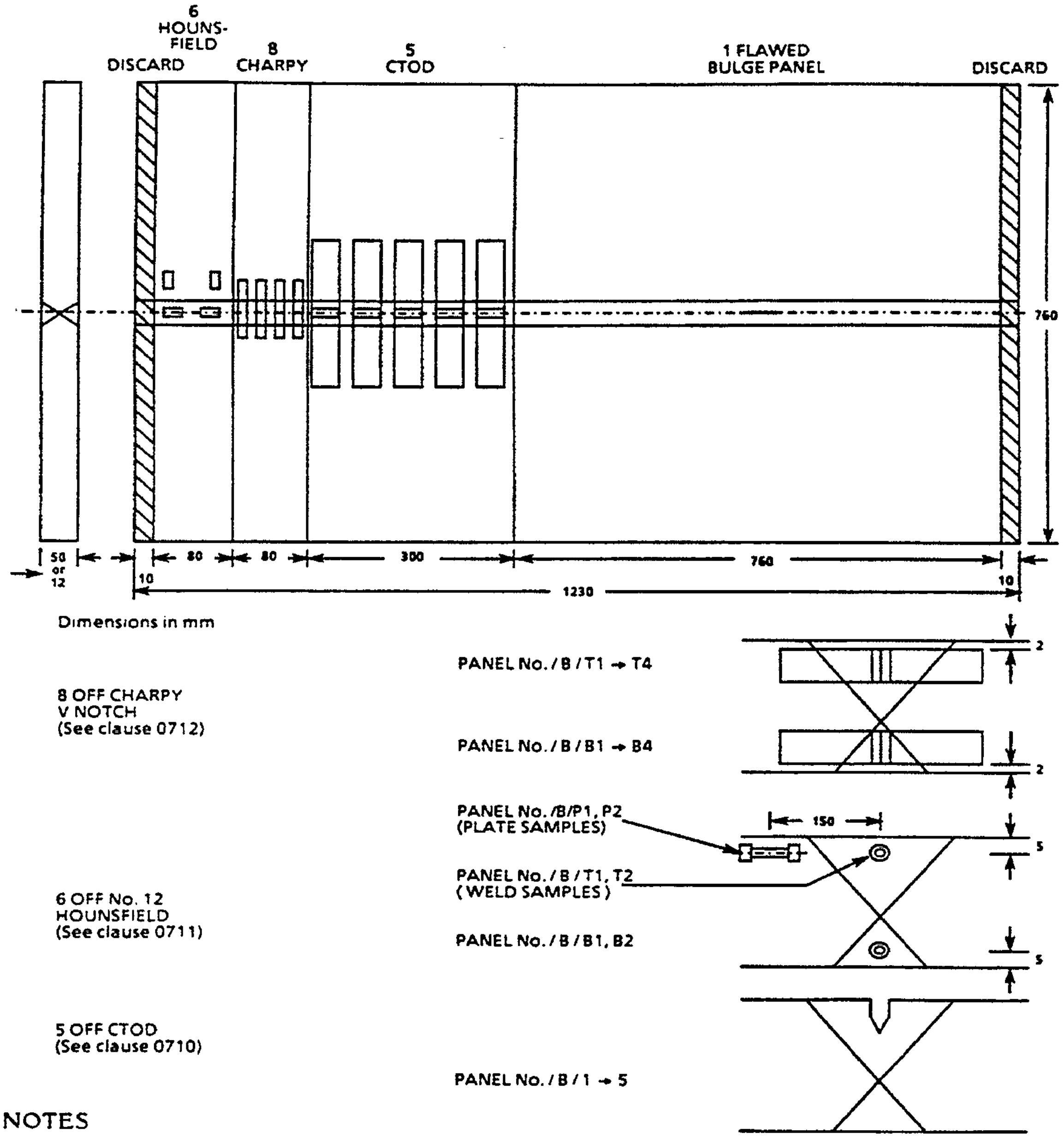
Submarine Class	Steel Type	PS MPa	UTS MPa	EL %	Cv	CE
A Class Amphion	S	285	460	20	-	0.49
P Class Porpoise	UXW	387	575-665	15	27J at -20°C	0.59
O Class Oberon	QT28	430	540-695	20	61J at -20°C	0.52
SSN01 Dreadnought	QT35	550/650	1.1x 0.2%PS	20	81J at -40°C	0.70
SSBN Resolution	HY80	550/690		20	75ft lbs at -84°C	0.85
SSK, SSN SSBN Upholder Trafalgar Trident	Q1N	550/650	< 0.88 PS/UTS	20	101J at -84°C	0.85
Q1N Weld Metal	**SMA FCAW Sub Arc GMA**	> 550		20	55J at -55°C	

Table. 3 Typical Deposited Weld Metal Compositions

Process Type	Company and Consumable Name	C	Mn	Si	S	P	Ni	Cr	Mo	V
SMA	Murex Fortrex 11018	0.04	1.27	0.20	0.009	0.012	2.05	0.12	0.32	0.016
SMA	Murex Fortrex NQ1	0.05	1.50	0.35	0.010	0.014	0.82	0.01	0.21	0.006
SAW	Oerlikon OES3NiMo1 wire & OP12TT flux	0.072	1.09	0.30	0.006	0.012	1.33	-	0.53	-
FCAW	Alloy Rods Dualshield 101 TM wire with Argon 5% CO_2 shielding gas	0.08	1.09	0.34	0.009	0.006	1.80	0.08	0.03	0.03

Table. 4 Typical Deposited Weld Metal Properties

Process Type	Company and Consumable Name	0.2%PS MPa	UTS MPa	Elong. %	Charpy. Joules at Test Temp.
SMA	Murex Fortrex 11018	644	718	20	75, 67, 65. at -20^{0}C
SMA	Murex Fortrex NQ1	594	675	22	121, 116, 136. at -50^{0}C
SAW	Oerlikon OES3NiMo1 wire & OP121TT flux	660	780	20	120-136, at -20^{0}C 70-90, at -50^{0}C
FCAW	Alloy Rods Dualshield 101TM wire with Argon 5% CO_2 shielding gas	599	660	21	106-122, At -20^{0}C 70-85, at -50^{0}C



NOTES

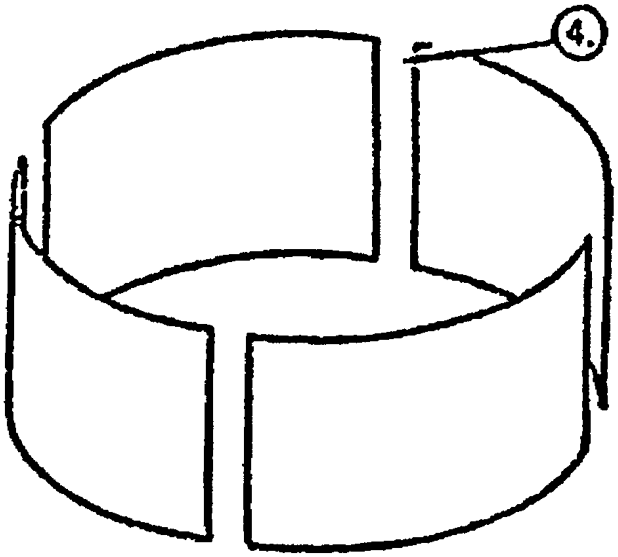
1. Preparation to be identical to weld procedure.

2. Test panel length can be reduced when either FBE or CTOD are not required.

3. For procedures to weld plate of 20mm to 100mm thickness the test plate thickness is to be 50mm, below 20mm the test plate thickness is to be 20mm.

Figure 1 Weld Procedure Approval Plate

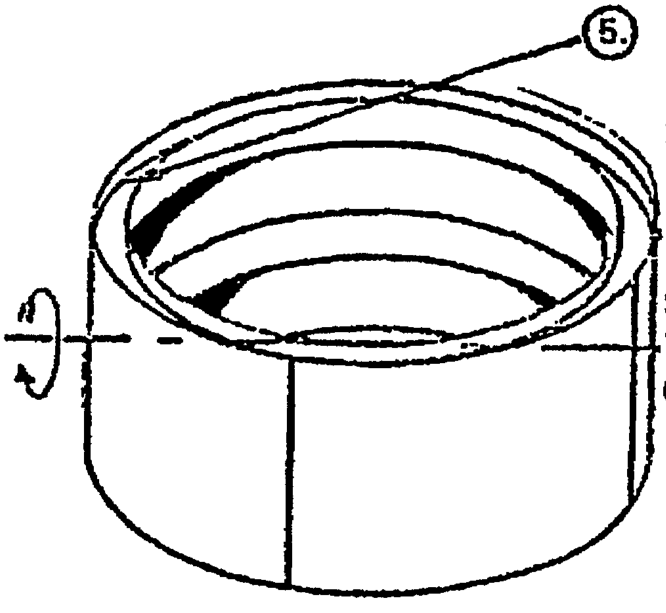
A. SHELL WELDING FIXTURE



WELD SHELL SEAMS
FULL PEN. WELD
2 SIDES, DOUBLE VEE

BACKGOUGE

B. FRAME INSTALLATION FIXTURE



WELD FRAMES TO SHELL
FULL PEN. WELD
2 SIDES, DOUBLE VEE
ROOT PASS
FILL PASSES – AUTO
SUB ARC
TURN FOR AUTO BACKGOUGE & 2ND SIDE WELD

Figure 2 Build Sequence