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WELDING PROCEDURE FOR TOOTH AND SHROUD ADAPTERS TO BUCKET LIPS

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1. INTRODUCTION

When attaching Keech Alloy KL and KH Tooth Adapters and Shroud Adapters to Bucket Lips, there are a number of issues that must be considered to ensure the successful welding of both materials.

- Both the KL and KH castings and the wrought lip plates are made from thick, high strength, high toughness, quenched and tempered alloy steels. Hydrogen controlled welding procedures are essential to avoid hydrogen assisted cold cracking (HACC) in the parent metal heat affected zones and the weld metal.

- The materials are required to have good toughness to perform in an environment where high strain rate loading (shock loading) is predominant. Minimum pre-heat, minimum interpass and maximum interpass temperatures must be strictly maintained to both preserve the properties of the parent materials and achieve satisfactory microstructures and mechanical properties in the heat affected zones.

- Selection of welding consumables must be made to ensure satisfactory properties in the weld metal. Toughness and resistance to hot and cold cracking are prime requirements. Failures due to lack of tensile strength are uncommon.

- Tooth adapters should fit well to the lip plate with good contact on the bevel and the top leg with a maximum gap of 3.0 mm at the bottom leg. It is particularly important to achieve a minimum gap on the bottom or tension leg of the adapter.

- Weld preparations should be made with great care to ensure cleanliness of surfaces to be welded. If air arc gouging is used it is essential that all surface and subsurface carbon is removed, usually by grinding. These materials have very high carbon equivalents and are intolerant to carbon pick-up.

- For tough, crack free welds, preparations must have the correct shape to achieve an ideal depth to width ratio of each weld bead. Welds should be placed in stringer beads with little or no weaving. Ideal depth-to-width ratios are 0.8 to 1.2.

- In order to achieve tempered martensitic structures in the parent metal heat affected zones (HAZs) temper bead welding techniques must be used. Temper beads should be placed on the face of fillet welds, overlapping the final pass in the weld toe to provide reheating of the HAZ at the weld toe.

- Welds should be dressed across the face with particular attention to smooth concave profiles at the weld toes. Any grinding/burring marks should be aligned with principal stresses i.e. normal to expected crack locations. Weld terminations should be dressed and be of a form that minimises stress concentration at the weld run out.

- Non-destructive testing should be carried out on the surface of finished welds. Welds should be free of cracks, lack of fusion, porosity, undercut or any other surface breaking discontinuity.

2. SCOPE

This weld procedure has been developed for the attachment of Keech Alloy KL and KH Tooth Adapters and Shroud Adapters to high strength alloy steel bucket lips.

3. MATERIALS

3.1 TOOTH ADAPTERS AND SHROUD ADAPTERS

Tooth Adapters and Shroud Adapters are made from Keech Alloys KL and KH with a carbon equivalent 0.71 and 0.67 respectively, calculated on typical chemical composition. Alloy KL is quenched and tempered at 200°C and any subsequent re-heating in excess of 200°C could result in reduction of hardness and tensile strength. This does not apply to the KH alloy which is tempered at a much higher temperature.

3.2 BUCKET LIPS

The bucket lip steel is a Ni-Cr-Mo alloy steel, quenched and tempered to provide high tensile strength, high yield to ultimate strength ratio with high toughness. Carbon equivalent can vary from 0.6 to 0.8. It is recommended that if the carbon equivalent of the lip plate is not known, then a check with the material supplier should be made to confirm chemical composition.

3.3 WELDING CONSUMABLES

Welding is carried out using either manual metal arc welding (MMAW), gas metal arc welding (GMAW) or flux-cored arc welding (FCAW). Recommended welding consumables are as follows:

TABLE 3.1 RECOMMENDED WELDING CONSUMABLE SPECIFICATIONS

WELDING PROCESS	CLASSIFICATION AS	CLASSIFICATION AWS
MMAW	AS1553.1 E4818-3H_{10}	AWS/AME-SFA 5.1 E7018-1H_4
GMAW	AS 2717.1 ES6-GC/M-W503AH	AWS/ASME-SFA A5.18 ER70S-6
FCAW	AS 2203.1 ETP-GCn/p-W503A.CM1 H_5	AWS/ASME-SFA A5.20 E71T-5MJ H_4

The above welding consumables provide good strength and tolerance to pick-up of carbon and alloys due to dilution from the parent metals and should maintain adequate toughness. Where an increase in overall weld strength is necessary, an increase in weld throat thickness is recommended rather than an increase in weld metal tensile strength.

The use of higher strength welding consumables is usually not necessary and could lead to significant reductions in toughness and ductility. Where a higher strength consumable is selected, it should not be used for the first, and possibly the second, layer of weld metal onto the alloy steel lip or casting. A buttering layer using a consumable selected according to the Table above, should be applied before attempting to weld with higher strength materials, otherwise the first layers of weld metal will be too highly alloyed and crack prone.

Welding consumables shall be stored, conditioned and used strictly in accordance with the manufacturer's recommendations to maintain low hydrogen conditions.

4. PRE-HEATING / INTERPASS TEMPERATURES / POST-WELD HEAT TREATMENT

4.1 PRE-HEATING

Pre-heating is used to reduce the cooling rates immediately after welding to avoid the formation of hard and brittle martensite. Higher pre-heats are necessary with increasing carbon equivalents (hardenability) and increasing section thickness (self quenching rate).

Pre-heating should be applied to establish an even temperature around the weld zone to a distance 3 x thickness of the lip plate from the weld centre line. Care must be taken to ensure that local hot spots are not created, as this will cause isolated softening of quenched and tempered materials.

Minimum pre-heat temperatures shall be as shown in Table 4.1.

Note: The minimum preheats are only suitable for multiple pass welds where temper beads are used to modify as welded HAZs in parent materials.

Table 4.1 RECOMMENDED PRE-HEAT AND INTERPASS TEMPERATURES

Carbon Equivalent	Weldability Group Number	Minimum Pre-heat & Interpass Temperature °C	Maximum Interpass Temperature °C
0.60 to below 0.65	8	140	200
0.65 to below 0.70	9	160	200
0.70 to below 0.75	10	175	200
0.75 to below 0.80	11	190	200
0.80 and above	12	200	200

4.2 INTERPASS TEMPERATURE

Minimum interpass temperature shall be the same as the minimum pre-heat temperature and shall be maintained until all welding is complete. Maximum interpass temperature shall be as shown in Table 4.1.

4.3 POST-WELD HEAT TREATMENT

Post-weld heat treatment shall be applied in a controlled manner to ensure that the pre-heat temperature range is maintained for a minimum of two (2) hours after completion of welding, followed by a slow cool.

5. WELDING PROCEDURE

All welding shall be carried out by competent persons under adequate supervision, in accordance with documented welding procedures. All details of the welding procedure should be verified. Correct application of pre-heat and interpass temperature is critical with these materials to reduce cooling rates during welding and limit the formation of high hardness, low toughness martensitic microstructures. Welding parameters shall be in accordance with consumable manufacturer’s recommendations for the size and position used.

In order to achieve tempered martensitic structures in the parent metal heat affected zones (HAZs) temper bead welding techniques must be used. Temper beads should be placed on the face of fillet welds, overlapping the final pass in the weld toe to provide reheating of the HAZ at the weld toe. In all cases any weld bead contacting parent materials should have a following tempering bead. Correct placement of the tempering bead should provide a tempering pass to the HAZ on the parent material.

6. AVOIDING CRACKING

6.1 HOT CRACKING

Hot cracking typically appears in the root area of a weld and may extend through the throat normal to the face of the weld. Tensile loading at the root of a weld or interrun shrinkage typically provide the stress needed for cracking. The tendency for crack formation is promoted by poor bead shape or contaminants such as gouging carbon or lubricants. Cracking is typically apparent during, or shortly after, welding.

The shape (depth to width ratio) of the weld bead in the root pass is critical to avoid cracking either at the fusion zones or at the weld centreline. Welds should be placed in stringer beads with little or no weaving. Ideal depth-to-width ratios are 0.8 to 1.2.

Hot cracking is prevented by ensuring weld preparations are the correct shape, weld beads are the correct shape and there are no sources of contaminants. Restraint and resulting contraction stresses in these types of weldments cannot be avoided.

6.2 HYDROGEN ASSISTED COLD CRACKING (HACC)

Hydrogen assisted cold cracking usually appears to be initiating, at or near to, toe of a weld and propagating into the heat affected zone of the parent metal. They may also occur in weld metal if higher strength weld metals are used. Crack location is usually in the heat-affected zone (under bead cracking).

Cracking is due to a combination of high residual stress, hydrogen contamination and crack susceptible microstructures. Cracking is usually prevented by use of sufficient pre-heat to retard the formation of martensitic structures and allow sufficient time at temperature for hydrogen diffusion after weld metal solidification. Restraint and resulting plastic strains during weld metal cooling cannot be avoided.

Hydrogen controlled welding practices are essential.

6.3 FATIGUE CRACKING

Weld zones typically have high levels of residual tensile and compressive stress due to localised shrinkage strains resulting from thermal contraction during weld metal cooling. Service loading may cause initial tensile and compressive yielding. Cyclic stresses, whether compressive or tensile, inevitably cause cycling tensile stresses at some location in the weld area.

Local cyclic stresses may therefore be tensile even under a nett compressive load, leading to fatigue cracking if there is sufficient tensile stress in a local area. Fatigue cracking may be initiated in weld zones by welding defects such as lack of fusion, hot or cold cracks, stress concentration from poor geometry or stress concentration from variations in metallurgical properties. Poor finishing of weld terminations or poorly finished weld toes are typical locations for fatigue crack initiation.

Elimination of fatigue cracking relies on an understanding of the conditions of initiation of a fatigue crack. Fatigue cracking is usually avoided by good design of weld profiles, minimising metallurgical stress concentrations, and attention to weld terminations with careful blending of finished welds in peak stress areas, such as fillet weld toes. Peak stresses acting in a weld must also be limited. Refer AS4100 – 1998 TABLE 11.5.1(2).

6.4 BRITTLE FRACTURE

Brittle fracture occurs due to lack of toughness under high strain rate loading (shock loading) conditions and may occur through weld metals, or more commonly through high hardness HAZ. Weld metals can become embrittled by excessive pick-up of alloys from the parent metals and by hydrogen contamination. HAZs are embrittled by excessive cooling rates and hydrogen contamination.

Brittle fracture is avoided by ensuring the weld metal and HAZ have adequate toughness at the service temperatures of the equipment and low hydrogen welding is used. This is achieved by adequate pre-heat, avoiding contamination and selection of suitable hydrogen controlled welding consumables.

The use of smaller well shaped beads is preferable to larger beads due to the grain refining effect of successive weld passes.

6.5 DUCTILE FRACTURE

Ductile fracture occurs due to lack of tensile strength under low strain rate loading and is characterised by visible plastic deformation preceding fracture. This type of failure is rarely seen in practice and is the only failure mechanism that will be avoided by an increase in weld metal tensile strength. Unnecessary increases in welding consumable tensile strength usually result in a reduction of ductility and toughness, particularly if parent metal dilution enriches the weld metal chemistry.

7. DESIGN

Some designs call for the welds to be terminated at some distance back from the leading edge of the lip plate to reduce the peak stresses applied to the runout of the fillet weld.

The termination of the fillet is shaped by careful blending to minimise stress raisers at the toe and root positions. The preferred shape is for the end of the fillet weld to be vertical, ensuring full throat thickness at the end of the weld. The weld should transition to the casting and plate edge with a smooth notch free radius. Additional welding should be placed in these areas and then be carefully dressed back to achieve a contour that generates minimal stress concentration.

FIT-UP OF TOOTH ADAPTERS

Tooth adapters should fit well to the lip plate with good contact on the bevel and the top leg, and should achieve a maximum gap of 3.0 mm between the bottom leg and the lip plate. The ideal bottom leg gap is zero but some clearance is necessary to accommodate variations in castings and lip plates. Excessive gaps will lead to difficulty in achieving sound root runs and allow flexing of the adapter under load. It is particularly important to achieve a minimum gap on the bottom or tension leg of the adapter.

The size between the legs of the adapter castings is expected to be nominal plate size + 1.5 mm. - 0 mm. and the castings will fit a nominal size lip plate. The lip plate is expected to be nominal size + 0 mm. - 1.5 mm. The lip plate size can be achieved by machining where required.

Ensure the gaps are suitable for welding, such that an acceptable bead shape is produced. Where excessive gaps exist, packing plates or butter welding should be used.

The root run will typically contain approximately 70% welding consumable, 15% tooth adapter material and 15% plate material. The first pass will therefore be the most highly influenced by pick-up of carbon and alloys from the parent metals.

Subsequent passes will mix with less parent metal and have a chemistry closer to that expected from the welding consumable alone.

It is essential that when there are excessive root gaps, the parent metal be built-up to reduce the gap before a bridging weld is attempted. This approach will usually prevent a crack in the root run.

7.1 WELD PREPARATION

Weld preparations should be sufficiently open to allow easy access for welding and achieving good bead shapes. Deep narrow preparations must be avoided as they promote centreline cracking. Wide weaving should be avoided as this leads to micro cracking and reduction in weld metal toughness.

8. WORKMANSHIP

Cleanliness of the worksite is essential to avoid any sources of contamination in the weld metal. Highly alloyed materials are far less tolerant to contamination than the lower strength structural steels.

The welding equipment should be well maintained to ensure all connections in the welding circuit, including the work return clamp, are working efficiently enabling clean arc starting and consistent welding current.

To avoid cold starts and start porosity when using the GMAW and FCAW processes, it is recommended that the electrode wire be trimmed back to the contact tip before starting each weld run. This has the effect of providing a sharp chisel point on the wire that will initiate a clean arc immediately on contact with the parent metal and ensures that there has been sufficient time for a stable cloud of shielding gas to form around the wire before contact with the parent metal and commencement of welding.

For the MMAW process, clean starting and maintaining a consistent short arc is necessary to ensure good fusion and consistent shielding. Arc strikes out of the groove should be avoided.

Completion and dressing of welds is critical to extend life of welds in cyclic highly loaded applications. Improving the shape of the site where cracking initiates is the key. Blending to reduce the tendency to root cracking is very difficult due to poor access.

9. RESIDUAL STRESS

Residual stress is an inevitable consequence of fusion welding. Weld zones typically have high levels of residual tensile stress due to localised shrinkage strains resulting from thermal contraction during weld metal cooling. Residual stresses in heavy section, highly restrained weldments typically approach the yield point of the materials. Initial tensile loads imposed in service add to this residual stress and cause localised yielding.

Pre-heating and welding heat input can be used to reduce the extent and adverse effects of residual stress. Negative effects of residual stress can also be minimised by welding sequences.

Consideration should also be given to methods that result in a residual compressive stress on surfaces where fatigue cracks are likely to initiate.

10. NON-DESTRUCTIVE TESTING

Completed welds should be examined by magnetic particle or liquid penetrant techniques. Welds should be free of cracks, lack of fusion, porosity, undercut or any other surface breaking discontinuity.