

Welding Consumables for Lean Duplex Stainless Steels

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Keywords

Lean duplex stainless steels, LDSS, arc welding, welding consumable

Abstract

Lean Duplex Stainless Steels (LDSS) are finding more widespread use for two reasons: firstly the modified alloy content (low Ni and Mo) results in lower cost and secondly the higher strength (compared to austenitic stainless steel) allows reductions in section thickness. Consequently there is increasing use of LDSS, not only to replace standard austenitic stainless steels, but also in the growing field of structural applications where duplex stainless steels are selected for their superior combination of mechanical and corrosion properties compared to carbon and low alloy steels. To fully exploit the use of LDSS it is important to be able to join them and this paper will compare the alternative arc welding consumables that could be used.

A number of consumables could be used for joining LDSS, including 2209, 309L and 'matching' consumables; the relative merits of the different types will be discussed. The 2209 and 309L consumables are already well established whereas the matching consumables are obviously new and although described as matching have a somewhat different composition to the LDSS base materials and these differences are discussed. The properties of the different types of consumables will be compared with those of the base materials.

The data that is presented is primarily for the Manual Metal Arc/Shielded Metal Arc Welding (MMA/SMAW) and flux cored wire (FCW) processes. The LDSS are mainly finding use in structural applications and not aggressive corrosive environments so the emphasis is on the comparison of the tensile properties of the weld metals but impact properties are also reported. Although in the current rapidly changing economy it is difficult to provide exact cost comparisons an effort is made to compare the relative costs of the candidate consumables because cost is such an important factor in the selection of these alloys.

It is concluded that although 2209 types are suitable there could be cost advantages in using matching consumables. There are currently no national specifications for consumables matching LDSS so recommendations are given for a composition for newly developed consumables that would be suitable for welding all of the current LDSS.

1 Introduction

In the current economic environment small cost reductions can provide significant advantages and it is because of this that the LDSS have seen a rapid growth in use. The demand for LDSS was further increased by the recent increase in nickel price. With this increasing growth in the use of the base materials there has inevitably been a corresponding rise in the amount of welding that has been carried out and this has seen an increasing demand for matching weld metals.

The LDSS base materials have the same duplex ferritic-austenitic microstructure as the more familiar 2205 (S32205/S31803) alloy but this microstructure is sometimes achieved by the use of manganese rather than nickel. Most of the LDSS alloys also have most of the molybdenum removed, which further reduces the alloy cost. These changes in alloying produce a material which has similar strength to standard duplex alloys but reduced corrosion resistance, although corrosion performance is generally claimed to be as good as 304L/316L. The relative resistance to pitting corrosion can be judged from the calculated pitting resistance equivalent (PRE) number.

A number of LDSS alloys are listed in Tables 1 and 2 along with austenitic and standard duplex alloys for comparison.

Table 1: Composition ranges for a selection of common stainless steel alloys.

Alloy type	UNS Number	C	Mn	Cr	Ni	Mo	Cu	N	Minimum PRE *
200 series	S20100	0.15	5.5-7.5	16.0-18.0	3.5-5.5	--	--	0.25	16
	S20153	0.03	6.4-7.5	16.0-17.5	4.0-5.0	--	1.0	0.10-0.25	18
300 series	S30403	0.030	2.0	18.0-20.0	8.0-12.0	--	--	--	18
	S31603	0.030	2.0	16.0-18.0	10.0-14.0	2.0-3.0	--	--	23
LDSS	S32001	0.030	4.0-6.0	19.5-21.5	1.0-3.0	0.60	1.0	0.05-0.17	20
	S32304	0.030	2.50	21.5-24.5	3.0-5.5	0.05-0.60	0.05-0.60	0.05-0.20	22
	S32101	0.040	4.0-6.0	21.0-22.0	1.35-1.70	0.10-0.80	0.10-0.80	0.20-0.25	24
	S32003	0.030	2.0	19.5-22.5	3.0-4.0	1.5-2.0	--	0.14-0.20	27
Duplex	S31803	0.030	2.0	21.0-23.0	4.5-6.5	2.5-3.5	--	0.08-0.20	30
	S32205	0.030	2.0	22.0-23.0	4.5-6.5	3.0-3.5	--	0.14-0.20	34

$$PRE = Cr + 3.3Mo + 16N$$

* This is the minimum PRE that could be achieved with the composition range of the specification. There are often additional restrictions imposed eg. For S32205 a minimum PRE of 35 is often specified.

Table 2: Minimum strength requirements for a selection of common stainless steels taken from ASTM/ASME standards for base materials and AWS/EN standards for welding consumables.

Alloy	Yield Strength MPa	Tensile Strength MPa	Elongation %	Max hardness HB
S30403	170	485	30	--
S31603	170	485	30	--
S32001	450	620	25	290
S32304	400/450 #	600/690 #	25	290
S32101	450	650	30	290
S32003	450	620	25	290
S20100	275	515	40	--
S31803	450	620	25	290
S32205	485	655	25	290
AWS: 308L	--	520	35	--
EN:19 9 L	320	510	30	--
AWS: 316L	--	490	30	--
EN; 19 12 3 L	320	510	25	--
AWS: 2209	--	690	20	--
EN; 22 9 3 N L	450	550	20	--
AWS: 309L	--	520	30	--
EN: 23 12 L	320	510	25	--
MMA matching *	650	800	32	--
FCW matching *	600	750	35	--

* Values for matching consumables are typical.

Minimum depends on product form (tube/pipe/plate).

Table 3: Composition ranges for the candidate welding consumables (ranges given for 309L and 2209 would meet AWS and EN standards).

Alloy type	Process	C	Mn	Cr	Ni	Mo	Cu	N #	Minimum PRE *
309L	MMA	0.04	0.5-2.5	22.0-25.0	12.0-14.0	0.75	0.75	--	22
	FCW	0.04	0.5-2.5	22.0-25.0	12.0-14.0	0.3	0.3	--	22
2209	MMA	0.04	0.5-2.0	21.5-23.5	8.5-10.5	2.5-3.5	0.75	0.08-0.20	31
	FCW	0.04	0.5-2.0	21.0-24.0	7.5-10.0	2.5-4.0	0.3	0.08-0.20	30
LDSS	MMA/FCW	0.04	0.5-2.0	22.5-25.5	8.0-10.0	0.1-0.8	0.1-0.8	0.08-0.20	24

PRE = Cr + 3.3Mo + 16N

2209 consumables are often specified with 0.14% minimum nitrogen.

* This is the minimum PRE that could be achieved with the given composition range. There are often additional restrictions imposed eg. For 2209 consumables a minimum PRE of 35 is often specified.

2 Consumables

The LDSS alloys were initially welded using the same consumables that were used for the 2205 duplex stainless steels which provided matching or overmatching properties compared to the LDSS base materials. But with growing use of LDSS's fabricators were increasingly asking for matching consumables.

The main candidates for welding LDSS were the already available 2209 duplex or 309L consumables, or a consumable matching the base material. Each of these types will be assessed based on properties and cost.

The 309L and 2209 consumables are well established, readily available, products that most people will be familiar with but the consumables matching the LDSS's are new and warrant some description before they are discussed further. As will be seen from Table 1 the LDSSs take a variety of forms but the most common types (S32304 and S32101) generally have low nickel, low molybdenum and some (eg. S32101) have high manganese. Although the consumables that are discussed here are referred to as matching they do not exactly match the LDSS base materials. The biggest difference being that they are higher in nickel than the base material (much as 2209 weld metals overmatch the nickel content of 2205 base material), see Table 3 for the composition range of the matching LDSS consumables proposed by the current authors.

3 Properties

3.1 Strength

One of the driving forces for the increased use of LDSS is their higher strength compared to standard austenitic stainless steels such as 304L and 316L. If the strength of the base material is to be utilised then the weld metal will need to match the strength of the base material.

The 309L type has been suggested as a candidate for welding LDSS but when the properties of 309L weld metals are compared to the requirements of the LDSS base materials it can be seen that they are not suitable for all grades, Figure 1.

As can be seen from Figure 1 the 0.2% proof stress requirement for a number of the base materials can be met by the 309L consumables but the tensile strength proves to be far more difficult to meet. It should also be taken into account that the strength requirements plotted for the LDSS base materials are the minimum requirements from ASTM standards and some proprietary alloys are produced to higher strength values. Based on the data presented in Figure 1 it is felt that the 309L type consumables are not a viable option as the standard choice of consumable for welding the LDSS base materials.

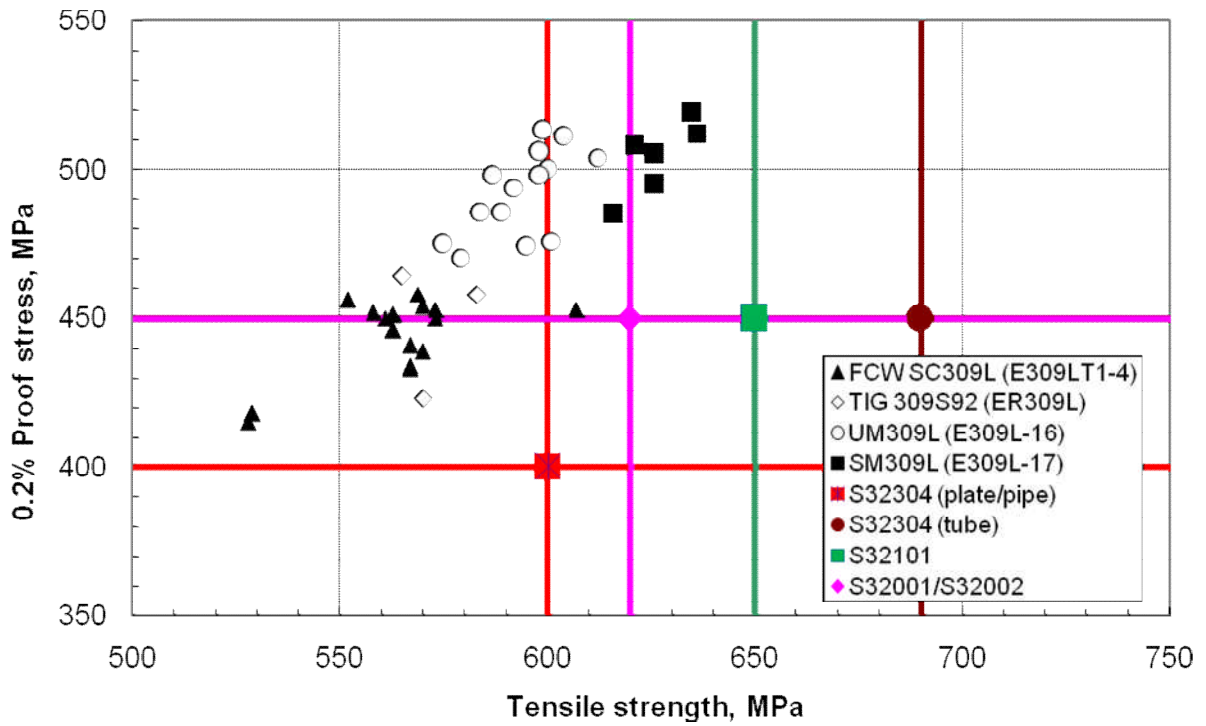


Figure 1: Actual strength of 309L weld metals in comparison to LDSS base material requirements.

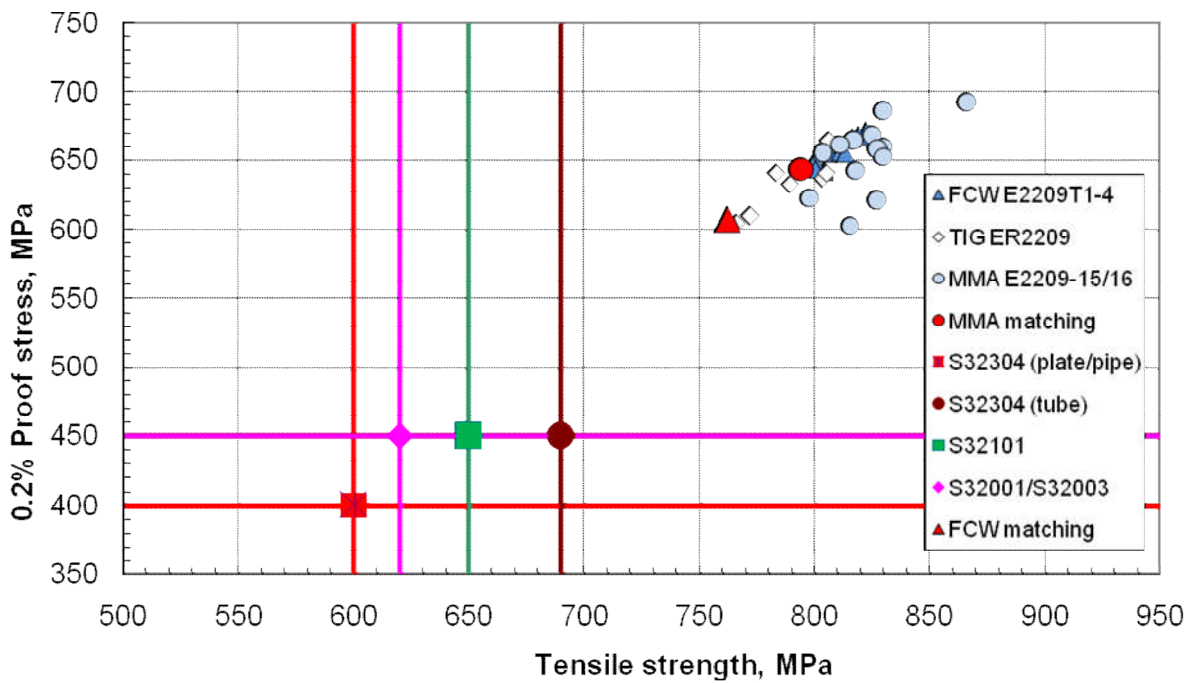


Figure 2: Actual strength of duplex and LDSS weld metals in comparison to LDSS base material requirements.

The second commonly available consumables that have been used for welding LDSSs are the 2209 types. The 2209 types are duplex and are capable of comfortably meeting the strength of the common grades of LDSS. As can be seen from Figure 2 the TIG, MMA and FCW processes meet the strength requirements of the common grades of LDSS.

The final alternative that will be considered is matching consumables. The tests that have been carried out to date on matching consumables show strengths comparable to the 2209 duplex consumables, Figure 2.

In addition to the strength the ductility (elongation) of the weld metal also has to be sufficient and the matching LDSS consumables had 4d elongation of 32-35% (5d 29-32%), which are above the minimum requirements currently specified for 2209 type consumables in AWS (20% on 4d) and EN (20% on 5d) standards.

3.2 Toughness

Having discounted the 309L types on the basis of strength, the impact properties of the 2209 and matching consumables will be considered. There is very little difference in the impact properties of the 2209 and matching weld metals as can be seen from Figure 3. The toughness of the 2209 types has been found to be adequate for many critical applications, including those in the offshore industry, so the values found for the matching consumables is expected to be satisfactory for most applications.

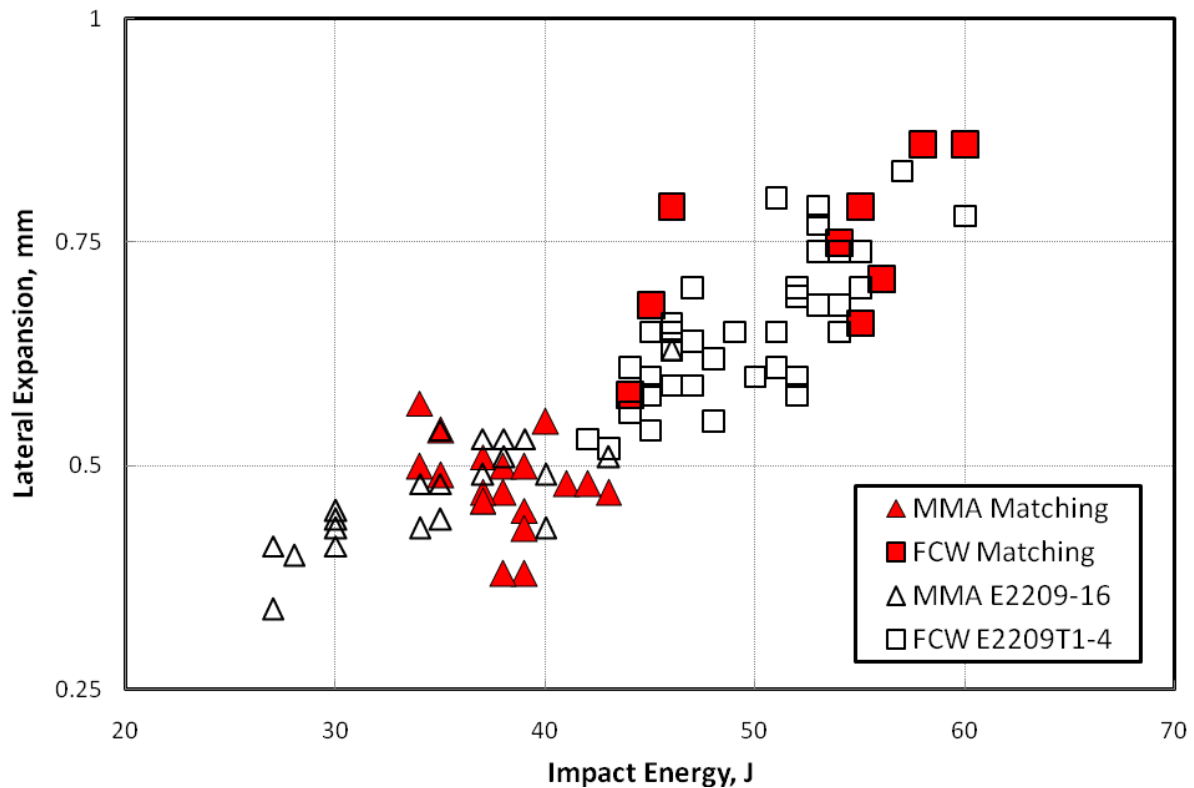


Figure 3: Impact properties for 2209 MMA/FCW and matching LDSS MMA/FCW consumables at -50°C.

The toughness of the weld metals for both standard duplex (2209) and LDSS types is limited by the flux system used. For optimum operability all of the consumables developed so far for LDSS have been rutile. In practice manufacturers of stainless steel flux cored wires always use a rutile flux system and with the flux cored wire process it is possible to achieve superior toughness compared to rutile MMA electrodes. However, compared to standard 22%Cr duplex weld metal, it is also evident that LDSS rutile electrodes tested during the current work will exceed 27J at -50°C.

3.3 Corrosion

No evaluation of corrosion performance has yet been carried out as part of the current work although it is planned to evaluate the weld metals using the ASTM G150 corrosion test. The proposed LDSS weld metal composition is designed to produce a minimum PRE of 24 which will match or exceed the most common LDSS base materials (S32001, S32101 and S32340) which have minimum PRE of 20-24, but it would fall short of the minimum PRE of 27 for the S32003 type which has 1.5-2.0% Mo.

3.4 Microstructure

The LDSS are designed to produce a ferritic-austenitic microstructure and a limited study has been carried out to examine the microstructure exhibited by flux cored wires of both the matching and 2209 types. As can be seen from Figure 4 the microstructure of the LDSS matching consumable is duplex ferritic-austenitic albeit slightly lower ferrite content than the standard 22%Cr duplex wire. The ferrite content of both the duplex and LDSS weld metals are given in Table 4.

Table 4: Ferrite content of weld metal deposited using E2209T1-4 and matching LDSS all-positional rutile flux cored wires.

Alloy	Location	Weld Metal Ferrite Content		
		Point Count, %	FN, Measured Ferritescope	Calculated FN, WRC
2209	Final bead (As-deposited)	52	58	52
	Mid-section (Reheated)	42	47	--
LDSS	Final bead (As-deposited)	47	32	32
	Mid-section (Reheated)	29	28	--


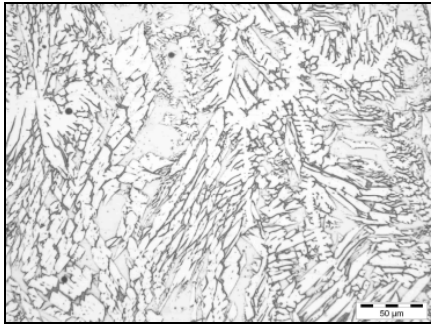
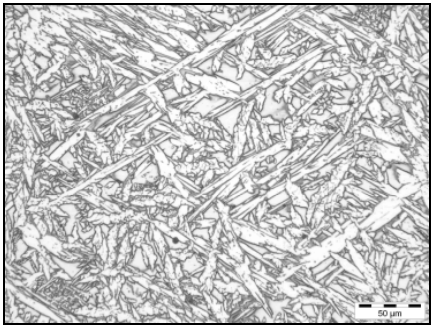
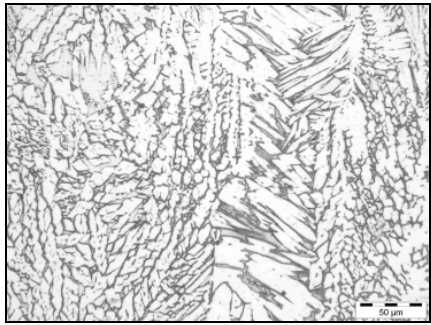
	Standard 22%Cr E2209T1-4 flux cored wire	Matching LDSS all-positional flux cored wire
Final bead (As-deposited)		
Mid-section (Reheated weld metal)		

Figure 4: Microstructure from deposits made using E2209T1-4 and matching LDSS all-positional rutile flux cored wires (original magnification x400).

3.5 Costs

The 2209 and matching consumables have both been shown to provide adequate mechanical properties for welding LDSS alloys. One of the driving forces for the increased use of LDSS is the recent increases in alloy costs, which has meant that LDSSs can provide significant cost savings.

Cost of base materials and welding consumables are not easy to compare because many factors affect the price of finished products in addition to the raw material cost. For example if the market for matching welding consumables was very small and the volumes required were not significant then the price of the finished product would be determined more by the fabrication cost of making a speciality product than the cost of the raw materials. The production costs could be a significant part of the finished product cost, particularly for solid wires where specific melts of materials would be required. MMA electrodes and flux cored wires would not be affected quite so much because alloying can be fined-tuned through the flux.

Table 5: Cost estimation (based on traded metal costs not on production costs).

Product	Alloy	2000 Cost (2205 in 2000 = 1.0)	2007 Cost (2205 in 2000 = 1.0)	2007 Cost (2205 in 2007 = 1.0)	Cost Increase 2000 to 2007
Base Material	S30403	1.0	4.2	0.8	4.1
	S31603	1.3	6.7	1.4	5.3
	S32205	1.0	5.0	1.0	5.0
	S32304	0.8	2.4	0.5	3.1
	S32101	0.6	1.4	0.3	2.5
Consumable	308L	1.0	4.2	0.9	4.1
	316L	1.3	6.9	1.4	5.3
	309L	1.3	5.4	1.1	4.2
	2209	1.3	6.3	1.3	5.0
	Matching	1.1	4.2	0.8	3.8

Despite these difficulties it was felt it would be useful to provide an approximate alloy and consumable costing based on the alloy costs (ie prices that nickel, molybdenum etc were being traded at). Average prices were taken for the relevant alloying elements in the years 2000 and 2007 and were compared to show the increase in cost of the materials and consumables, and also to show the comparative cost of the different consumables. The numbers given in Table 5 are not actual costs but are simply comparative using the cost of 2205 base material as the reference point (1.0).

What Table 5 shows is that alloy costs have gone up by a factor of 2.5-5.5 in the period 2000 to 2007. But because the standard 2205/2209 duplex products contain greater percentages of the higher cost elements these materials have shown a greater increase in cost compared to the LDSS types. Based on these approximate costing figures for large volume production there could be some benefits in the use of matching consumables, but the major saving will be with the base material. For the S32101 and S32304 base materials in 2000 they were 0.6-0.8 the cost of 2205 but in 2007 they are only 0.3-0.5 the alloy cost of 2205.

The consumable cost for 2209 was 1.3 the cost of 2205 base material in 2000 and this remains the same ratio in 2000. For the matching consumable in 2000 the alloy cost would have been 1.1 that of 2205 base material but in 2007 the alloy cost is 0.8 that of 2205 base material because of the low Mo content. This means that in 2007, based solely on material cost, the MMA/FCW matching LDSS consumables would be ~60% the cost of a 2209 consumable.

4 Conclusion

The growing use of lean duplex stainless steels (LDSSs) has increased the demand for suitable welding consumables. The current work investigated the suitability of three types of consumable for welding LDSS:

the commonly used dissimilar weld metal 309L

the standard 2209 duplex consumables

matching LDSS consumables of nominal composition: 0.03%C-1%Mn-24%Cr-9%Ni-0.2%Mo-0.2%Cu-0.15%N (see Table 3).

The following conclusions were drawn from the work:

- 309L consumables do not provide sufficient strength to exceed the requirements of the LDSS base materials so are not considered satisfactory for welding LDSS.
- The 2209 standard duplex consumables are a perfectly satisfactory choice for welding LDSS's but for large projects there is the potential for cost savings by using matching consumables.
- The matching LDSS Manual Metal Arc (MMA) and Flux Cored Wire (FCW) consumables developed have been shown to deposit weld metal that exceeds the tensile strength requirements of the currently available LDSS's (nominally 600-650MPa 0.2% proof stress and 750-800MPa UTS).
- The matching LDSS MMA and FCW consumables developed have been shown to deposit weld metal that has satisfactory toughness (>27J at -40°C).
- The matching LDSS MMA and FCW consumables developed have been shown to deposit weld metal that has a satisfactory duplex ferritic-austenitic microstructure containing ~30% ferrite (30FN).
- The matching LDSS MMA and FCW consumables developed deposit weld metal that has a pitting resistance equivalent (PRE) number in excess of 24 (actually 27 based on nominal composition) which matches the standard LDSS base materials.
- Based on current material costs the LDSS matching consumable is approximately 60% the cost of the 2209 type, although production costs could significantly affect the actual price of the consumable.
- There are a number of common grades of LDSS so rather than have a consumable dedicated to each grade a weld metal composition has been proposed, Table 3, that is satisfactory for the most commonly used types (S32101 and S32304). For the LDSS grades that contain higher Mo levels (eg. S32003) the 2209 consumables are considered the better option.