NORSOK Qualification of Duplex Stainless Steel Flange

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Abstract

Shimoda Iron Works, Ltd. has many experiences to supply Duplex Stainless Steel (DSS) flanges and fittings. Since DSS flanges have excellent corrosion resistance and high mechanical strength they are suitable for sever environments like subsea piping system of corrosive oil and gas. From this point of view, flanges made of two grades of DSS materials were manufactured and evaluated according to NORSOK standard. Their manufacturing process and investigation results are reported in this paper.

1. Introduction

Duplex Stainless Steel (DSS) has a matrix consist of austenite and ferrite in approximately same volume. DSS has both excellent corrosion resistance and high mechanical strength. Therefore DSS flanges are suitable for sever environments like subsea piping system of corrosive oil and gas.

Shimoda Iron Works, Ltd. has many experiences to supply DSS flanges and fittings. However, in order to supply these products to such kinds of oil and gas system, the products need to be qualified by the authorized organizations. From this point of view, the flanges made of two grades of DSS materials were manufactured and evaluated according to NORSOK standard. Since they were successfully qualified by NORSOK, their manufacturing process and the investigation results are reported in this paper.

2. Materials and products for qualification

2.1 Materials

Two grades of Duplex Stainless Steel are selected for NORSOK qualification. They are typical materials for DSS flanges. Their designations according to NORSOK standard are shown in the following:

1) 22Cr DSS: NORSOK M-630 MDS (Material Data Sheet) D44, ASTM A182 F51 (UNS S31803) / F60 (UNS S32750)[1)]
2) 25Cr DSS: NORSOK M-630 MDS D54, ASTM A182 F53 (UNS S32750)[2)]

Chemical compositions of these materials are shown in **Table 1**.

The former, A182 F51 and F60, are standard materials of DSS. Since chemical compositions of F51 and F60 are almost same as shown in the table, this material is designated by “F51/F60” in this paper.

The latter, ASTM A182 F53, is called Super Duplex Stainless Steel (SDSS). Increased chromium content gives the material superior corrosion resistance and, at the same time, increased nickel and nitrogen contents maintain the balance of ferrite and austenite structures.

Table 1 Chemical compositions (wt%)

NORSOK	ASTM Gr	UNS No.		C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu
M-630 D44	A182 F51	S31803	min.	0	0	0	0	0	21.0	4.5	2.5	0.14	-
			max.	0.030	1.00	2.00	0.030	0.020	23.0	6.5	3.5	0.20	
	A182 F60	S32205							22.0	4.5	3.0	0.14	
									23.0	6.5	3.5	0.20	
	Flange F51/F60		**Ladle**	**0.014**	**0.49**	**0.77**	**0.018**	**0.0005**	**22.53**	**5.54**	**3.13**	**0.161**	**0.14**
M-630 D54	A182 F53	S32750	min.	0	0	0	0	0	24.0	6.0	3.0	0.24	0
			max.	0.030	0.80	1.20	0.035	0.020	26.0	8.0	6.0	0.32	0.50
	Flange F53		**Ladle**	**0.014**	**0.29**	**0.76**	**0.023**	**0.0007**	**24.89**	**6.90**	**3.79**	**0.285**	**0.12**

2.2 Products

The following type of flange was selected for the qualification. Using the above introduced materials, flanges were manufactured by hummer die forging.

Flange type: 900lbs. 14B WN RF Sch.80 (ϕ640 x ϕ318 x H220)

3. Manufacturing process of the flanges

3.1 Raw materials

Round billets were imported from Europe for raw material of the flanges. Chemical compositions are shown in “Ladle” of Table 1. Billet diameter of F51/F60 was 300 mm and F53 was 350 mm respectively. The billets were cut into blocks of individual weight of 346 kg.

3.2 Forging

The flanges were manufactured by closed die forging. The forging was performed by two hummers installed in a domestic forging company according to our order requirements. **Table 2** shows the forging conditions and **Figure 1** shows the pictures of each forging stage.

The forging operation of F51/F60 needed three heats and F53 needed four heats. After forging, the products were quenched immediately in the water. No defect was found on the surface of the products.

Table 2 Hot working conditions

Stage	Equipment	F51/F60 (Block: ϕ300×610L)			F53 (Block: ϕ350×450L)			Pictures in Figure 1
		Heat	Temperature		Heat	Temperature		
Heating	Heating furnace	—	Furnace atmosphere	1,250℃	—	Furnace atmosphere	1,250℃	a)
Upsetting	3ton-m hummer	1st heat	Hot working temperature	1,180℃ -1,245℃	1st heat	Hot working temperature	1,060℃ ～1,195℃	b)
Die forging	8ton-m hummer	2nd heat			2nd heat			c)
					3rd heat			
Trimming & punching		3rd heat			4th heat			d)
Water quenching	Water bath	—	Just before quenching	1,051℃	—	Just before quenching	1,033℃	e)

Figure 1 Forging process

3.3 Heat treatment

3.3.1 Verification test of the furnace

Before the solution treatment of the flanges, a verification test was carried out in order to confirm the temperature distribution in the furnace. Twenty five (25) dummy flanges were prepared for the test as shown in **Figure 2**. The measurement result using several thermo couples on the dummy flanges is shown in **Figure 3**. According to the temperature chart, the maximum temperature difference from target temperature during annealing stage is seven (7) degrees. This means that the furnace is well controlled as a furnace for the solution treatment of stainless steel products.

Figure 2 Dummy flanges for verification

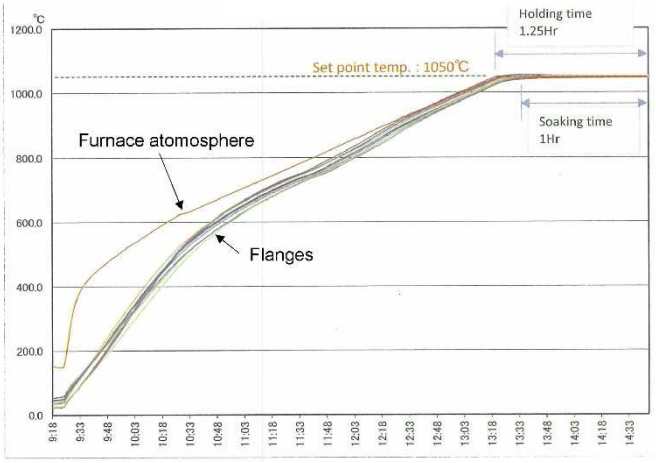

Figure 3 Temperature record chart

3.3.2 Solution treatment of the flanges

Solution treatment was made after forging. Heat cycle is shown in the following:

1,050 ℃ x 2 hours → water quenching

Surface temperature was monitored at three points of the flange during annealing. All temperature ranges were met within 1,050 ± 7℃ which was satisfactory to NORSOK standard.

Moreover NORSOK standard requires that the duration from furnace into quenching bath shall be less than 60sec and the water temperature of the bath shall be below 50℃. According to the measurement results during the quenching, it was confirmed that the transferring time was 53sec and the water temperature was kept under 50℃.

3.4 Finish machining

Following the solution treatment, a flange of each material was finished by machining. There was no difficulty when machining. After finishing, the penetrant testing (PT) was carried out. No surface defect was found.

Figure 4 shows the appearance of F51/F60 flange after PT.

Figure 4 Finished flange (F51/F60)

4. Investigations of properties

The following investigations were carried out according to NORSOK standards M-630 and M-650.[3)]

1) Tensile test
2) Impact test
3) Corrosion test
4) Microstructure observation
5) Ferrite content
6) Hardness (only for F53)

Sampling locations except hardness measurement are indicated in **Figure 5.** Position 1 is specified at middle of hub and position 2 at middle of flange respectively.

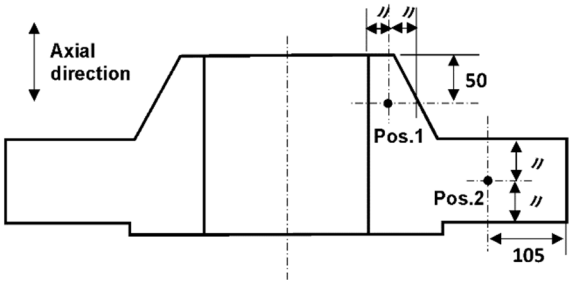

Figure 5 Sampling locations

4.1 Tensile test

Tensile test results at room temperature are shown in **Table 3**. At every position, properties are satisfactory to the requirements of NORSOK standards.

Table 3 Tensile test results

Grade	Product	Location	Direction	Y.S MPa	T.S MPa	El. %	R.A %
F51 F60	NORSOK	—		≧450	≧655	≧25	≧45
	Flanges	Pos.1	Tangential	519	728	37	75
		Pos.2		533	714	28	71
F53	NORSOK	—		≧550	≧750	≧25	—
	Flanges	Pos.1	Tangential	578	789	41	68
		Pos.2		565	770	35	65

4.2 Impact test

Charpy 2mm V-notch tests were carried out at -46 ℃. Sampling locations were pos.1 and pos.2 as shown in Figure 5. At each location, the specimens were sampled in axial and tangential directions. The results are shown in **Table 4** with requirements of NORSOK standards. All results meet the requirements successfully.

However, in the case of F51/F60 material, the results in axial direction at pos.2 are just above the minimum requirements. Therefore further study will be desired in order to increase the impact toughness in this condition.

Table 4 Impact test results

Sampling location	Direction	NORSOK requirements (J)			Flanges							
					F51/F60 (J)				F53 (J)			
		Temp.	Ind.	Ave	Ind.			Ave.	Ind.			Ave.
Pos.1	Axial	−46℃	≧55	≧65	227	269	319	272	221	267	292	260
	Tangential		≧20	≧27	125	145	205	158	140	147	213	167
Pos.2	Axial				21	30	34	28	55	58	60	58
	Tangential				167	171	203	180	103	117	122	114

4.3 Corrosion test

Corrosion tests were carried out according to ASTM G48 Method A - Ferric Chloride Pitting Test using the specimens sampled at pos.1 and pos.2. Testing conditions were 25 ℃ x 24 hrs for F51/F60 and 50 ℃ x 24 hrs for F53 respectively. **Table 5** shows the size of specimens and the test results of weight loss. As shown in the table, corrosion resistance of these materials are quite satisfactory.

Table 5 Corrosion test results

Grade	Location	Specimen				Testing condition	Weight loss		Pitting
		W	L	T	Area				
		mm	mm	mm	cm^2		mg	g/m^2	
NORSOK requirement		-	-	-	-	See below	—	<4.0	Not allowed
F51 F60	Pos.1	40.27	10.21	3.04	11.29	25℃ 24h	0.0	0.000	No
	Pos.2	40.27	10.22	3.10	11.36		0.2	0.176	No
F53	Pos.1	40.23	10.26	3.05	11.34	50℃ 24h	0.0	0.000	No
	Pos.2	40.23	10.26	3.06	11.35		0.0	0.000	No

4.4 Microstructure

Microstructure observation was made at the location of pos.1 and pos.2. As shown in **Figure 6**, every structure is austenite and ferrite duplex structure. Secondary austenite is observed in both materials however no intermetallic phase is found.

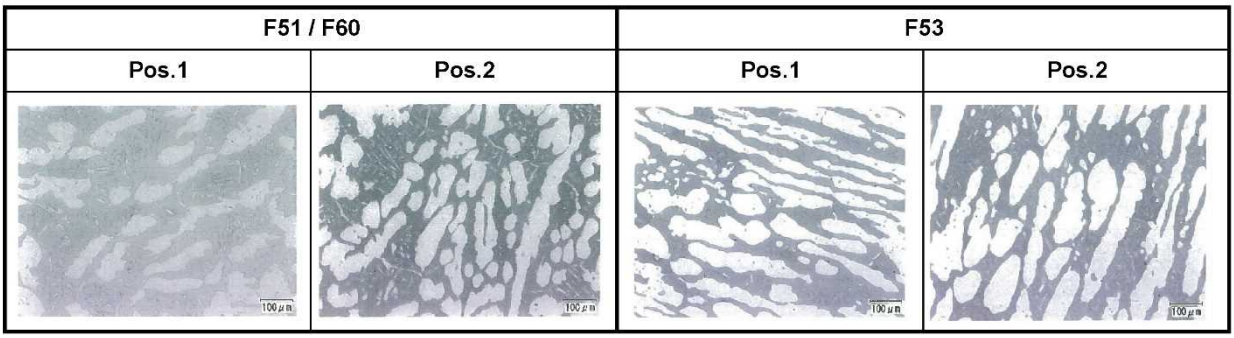

Figure 6 Microstructure

4.5 Ferrite content

Table 6 shows the results of ferrite content measurement. All of them are between 35 - 55 % which is required by NORSOK standards. Ferrite content of F53 is less than F51/F60.

Table 6 Ferrite content

Grade	Location	Ferrite content %
NORSOK		35-55
F51 F60	Pos.1	50
	Pos.2	50
F53	Pos.1	42
	Pos.2	39

4.6 Hardness

Hardness measurement was made only for F53 flange because ASTM A182 requires hardness range to be maximum HB300 for F53 material. All of the results at twenty five (25) points of the radial section were between HB 238 - 260 which meet ASTM requirement. Since NORSOK specifies no hardness requirement, this measurement is reference only.

5. Qualification

5.1 Qualification of the flanges

As reported above, all the properties satisfied the requirements of NORSOK standards. Based on these investigation data the flanges made of F51/F60 and F53 materials were qualified by NORSOK in August, 2017. **Table 7** shows the scope of qualification defined in Qualification Test Report (QTR) authorized by NORSOK.

5.2 Other qualifications by NORSOK

We have been working to obtain the qualifications of NORSOK for other products than flanges. We have already succeeded in NORSOK qualification of ring rolled products made of F51/F60 material. Moreover we are now developing a new manufacturing process by HIP (Hot Isostatic Pressing) treatment. Some products manufactured by HIP process will be prepared for qualification by NORSOK in the near future.

Table 7 QTR certified by NORSOK

Qualification Test Report		
QTR No.	SF-51QTR	SF-53QTR
Reference standard	NORSOK M-650, Edition 4	
Material designation and MDS No.	ASTM A182 Grade F51, UNS S31803 / F60, UNS S32205: MDS D44 Rev.5 Ferrite/ Austenitic Stainless Steel Forgings, Type 22Cr Duplex	ASTM A182 Grade F53, UNS S32750; MDS D54 Rev.5 Ferrite/ Austenitic Stainless Steel Forgings, Type 25Cr Duplex
Production and manufacturing process(es)	Die forged flange, Production route No.1	
Qualified date	4th August, 2017	
Qualification expired	3rd August, 2022	

6. Conclusion

The flanges made of two grades of duplex stainless steels, 22 Cr (F51/F60) and 25Cr (F53), were manufactured and evaluated according to NORSOK standards.

1) Forging by hummers needed three or four heats. There was no difficulty of hot working.
2) Solution treatment was successfully performed by the well controlled furnace.
3) There was no problem of finish machining.
4) All the investigation results meet the requirements of NORSOK standards.
5) These flanges are qualified by NORSOK as the die forged flanges.

References

1) NORSOK Standard M-630 Material Data Sheet MDS D44 Rev.5, Edition 6, Oct. 2013
2) NORSOK Standard M-630 Material Data Sheet MDS D54 Rev.5, Edition 6, Oct. 2013
3) NORSOK Standard M-650: Qualification of manufacturers of special materials, Sep. 2011