EXPERIMENTAL RESEARCH ON THE PROCEDURE FOR THE PREPARATION OF STANDARDIZED FORGED SEMI-FINISHED PRODUCTS IN USE IN UNDERWATER SYSTEMS

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The paper systematically presents the forging process for a MPS certified material in accordance with the DNVGL-RP-0034 standard.

API RP 6HT (Normalization, Austenitization, Tempering) thermal treatments were applied to the analyzed piece, and the sampling method and direction was performed according to DNVGL-ST-F101. The DNVGL-ST-F101 standard is important and widely used in the metallurgical field, especially in the field of forged semi-finished products for the extractive, natural gas, oil, maritime industry, etc. All mechanical features, including those obtained from SPWHT, are indicated on the finished product quality certificate.

Keywords: free forging; deformation degree, MPS, DNV-GL-RP-0034; API RP 6HT, DNV-GL-ST-F101.

1. Introduction

Forging means the procedure of processing a metallic semi-finished product by hot plastic deformation, without cracking, by means of static or dynamic forces exerted by presses or hammers [1, 3, 5]. Forging has the following advantages: rapid processing, low cost and simple workmanship. Disadvantages include the following: low dimensional accuracy, poor surface quality and the need for large deformation forces [2, 6, 9]. The main factor characterizing forging is the deformation degree (degree of strain).

Forging is classified according to the following criteria:

- the degree of freedom of the material during deformation: free forging, profiling forging on machines for limited use, forging in die;
- the working temperature: cold / hot;
- the deformation speed: low speed / high speed;
- the application of the deformation force: manual or mechanical.

In the free forging process the plastic deformation is made unlimitedly and can be done manually or mechanically. Mechanical free forging is applied in most of the small or single series forging sections [8, 10, 19].

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The standard regulating the forging process of special purpose metallic materials for underwater systems is DNV-GL-ST-F101.

The purpose of applying this standard is to guide the requirements of design and development concepts, the competent use of metallic materials and the effect of corrosion, coatings and protection in operation, mechanical operations and tests of the materials used, welding assembling, NDT control.

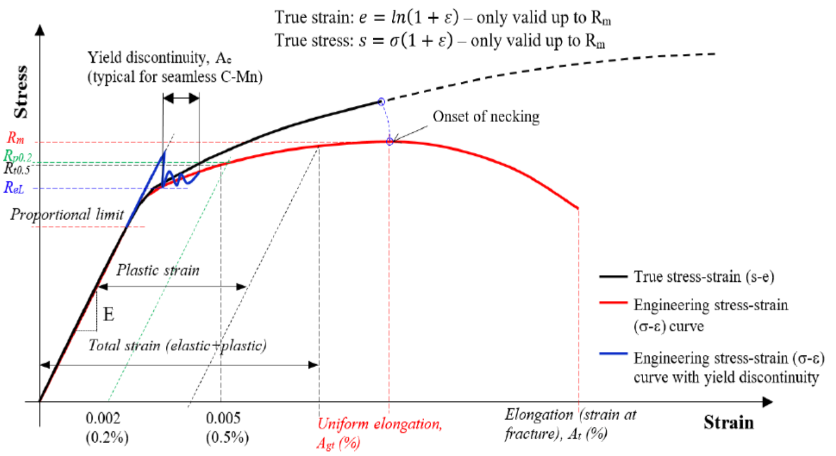

Fig. 1 Dependence of mechanical characteristics according to DNV-GL-ST-F101

The main objectives of the DNV-GL-ST-F101 standard are to ensure the development of the concept and the operations necessary to obtain the finished product in a regime of public safety and protection of the environment [11, 16, 20] to ensure international recognition of the use of special purpose materials by defining minimum requirements for product realization and to offer high tradability to both manufacturers and final costumers.

The applications of the DNV-GL-ST-F101 standard for the forged semi-finished products are multiple and vary depending on the industry in which the finished product operates (oil, natural gas etc.), the forged material used, the characteristics, the shape and dimensions of the forged semi-finished product, the mechanical characteristics necessary for the exploitation [11, 21, 22]. In this respect, a particular importance is given to the relationship between stress and strain represented in Fig. 1.

It can be observed the dependence of the mechanical characteristics: mechanical resistance and elongation, flow and plastic deformation of the material.

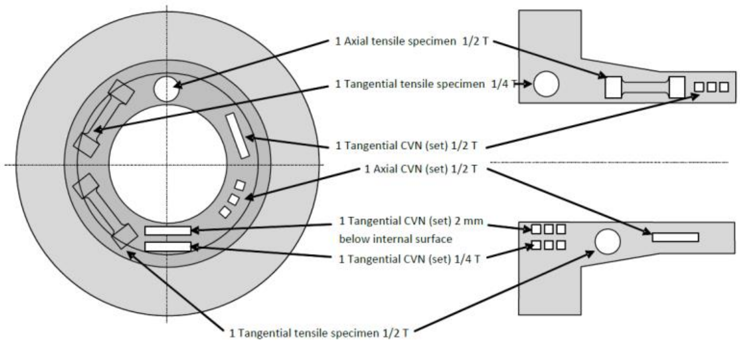

Fig. 2. Sampling method and direction according to DNVGL-ST-F101-QTC Sacricial part

Test specimens shall be removed as per DNVGL-ST-F101.
Mechanical test to be performed according to ASTM A370.

2. Experimental methodology

The objective of the procedure for obtaining special purpose forged semi-finished products is to ensure high transparency in the certification of the finished product and throughout the elaboration process and to ensure the superior certification of a third party at the Type 3.2 Certificate of material.

The need to implement the Preparation Procedure (MPS) is joining higher 3.2 standardized certifications on certain fields of exploitation of forged semi-finished products.

For the application of the DNV-GL-ST-F101 requirements standard in the experimental part was forged a piece with the shape and dimensions shown in Fig. 3 (drawing no. A452392 -18 Rev D).

Starting materials (ingots, rolled bars etc.) are selected in accordance with the specifications of material standards. The material is melted and prepared in an electric furnace followed by deoxidation (AOD) or vacuum arc remelting (VAR) [14, 15, 18]. The base material is AISI 4340 (the numbers of samples used for mechanical testing are provided in Table 1).

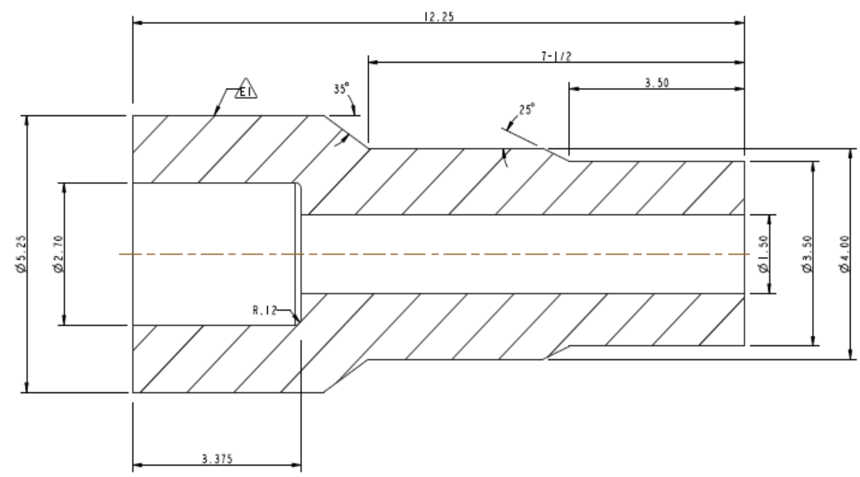

Fig. 3. The piece subject to MPS preparation in accordance with DNV-GL-ST-F101 (the dimensions of the drawing are in inches)

Table 1.

The samples subjected to MPS preparation in accordance with DNV-GL-ST-F101

Line item	**Part number**	**Dimensions**	**Quantity**	**Material**
1	A111827-14 rev.A RAW	A452392-18 REV.9	58	AISI4130
2	A111827-14 rev.A RAW*	AS RAW	2(SAC COMP.)	AISI4130

The chemical composition of the material used (AISI4130) is presented in the Table 2.

Table 2.

Chemical composition of the studied material (%)

Elements	**Min.**	**Max.**	**Ni**	-	0.25	**Ti**	-	0.025	**H**	-	2ppm
C	0.27	0.33	**Mo**	0.15	0.25	**Cu**	-	0.35	**O**	-	25ppm
Mn	0.3	0.7	**Al**	-	0.055	**V**	-	0.06	**$J^{(1)}$**	-	180
Si	0.15	0.35	**Sn**	-	0.02	**Nb**	-	0.02	**$X^{(2)}$**	-	20
P	-	0.015	**Sb**	-	0.03	**N**	-	0.012	**$CE^{(3)}$**	-	0.68
S	-	0.015	**As**	-	0.03	**Pb**	-	0.01			
Cr	0.75	1.2	**B**	-	0.001	**Bi**	-	0.01			

where:

$$1)\, J - Factor : (\%P + \%Sn) \times (\%Mn\%Si) \times 10^4$$
$$2)\, X - Factor : (10P[\%] + 5Sb[\%] + 4Sn[\%] + As[\%]) \times 10000\ /100$$
$$3)\, CE(CarbonEquivalent) : C(\%Mn/6) + (\%Cr + \%Mg + \%V)/5 + (\%Ni + \%Cu)/15$$

The forging procedure involves the starting material: AISI 4130 ingot type A900 (9500 kg), diameter = 780 mm, polygonal form. For this purpose, were used:

- Hydraulic forging press of 1600 tf with 15 tfkN manipulator;
- Electro-Hydraulic forging hammer of 3000 kgf;
- Gas required to heating the ingot.

The entire equipment for the preparation of the forged semi-finished product is calibrated. Each forging batch will be taken into account, the heating parameters are electronically controlled (contact thermocouple), a pyrometer is used to check the temperature before, during and after the last forging operation.

The forging process starts after reaching the optimal temperature:

- the initial temperature 1110-1150 ^oC
- the final temperature 890-850 ^oC

Stage 1 – Stretching process: polygonal equivalent middle section 875→Ø180 mm x L.

Hot work ratio: 23.6:1

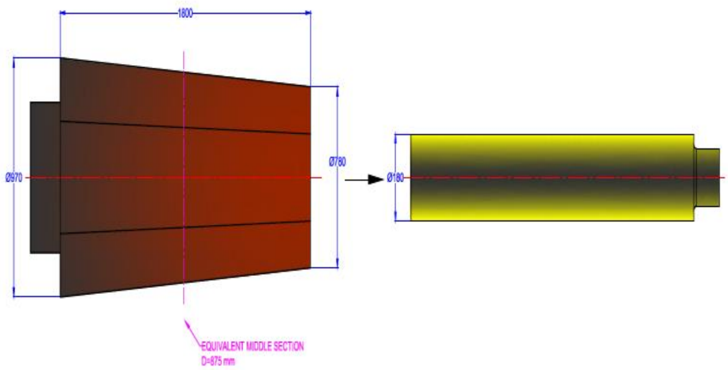

Fig. 4. Stage 1 of the forging process according to DNV-GL-ST-F101
(Hot work ratio: 23.6:1)

Stage 2 - Cutting the segments according to the weight of the forged semi-finished product at Ø180 mm x 170 mm (as shown in Fig. 5).

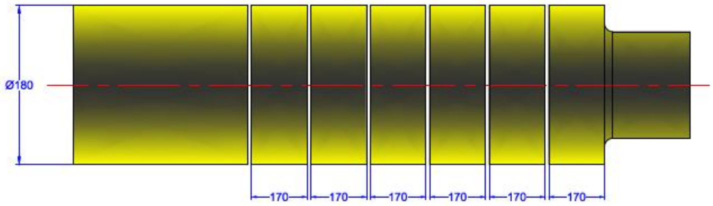

Fig. 5. Stage 2 of the forging process according to DNV-GL-ST-F101

Stage 3 - Reduction of the section from Ø180 mm x 170 mm to Ø143 x 270 (Fig. 6.)

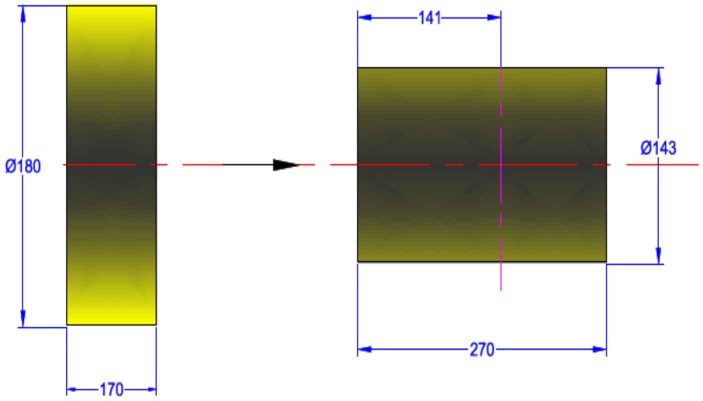

Fig. 6. Stage 3 of the forging process according DNV-GL-ST-F101

Stage 4 - Setup from Ø143 x 270 in order to obtain the final forging dimensions (Ø143 x 141) x (Ø112 x 191) presented in Fig. 7. Total degree of deformation 23.6 x 1.6 = 37.7:1.

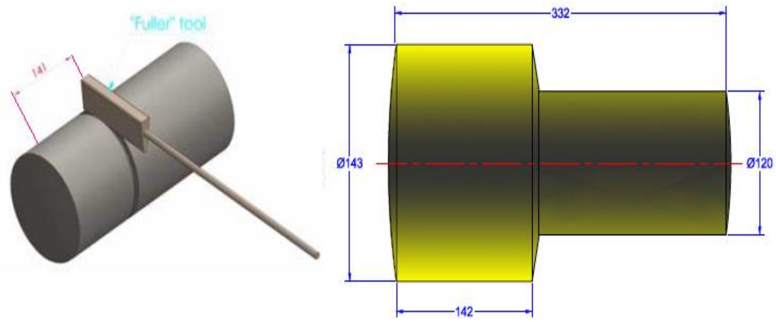

Fig. 7. Stage 4 of the forging process according to DNV-GL-ST-F101

The forged semi-finished products are cut to the dimensions of the client's specifications, on the appropriate machines to ensure the dimensional accuracy and surface quality required in the DNV-GL-ST-F101.

The secondary thermal treatment procedure is performed on a batch of parts of the same type (material quality) [13, 17]. The procedure is in accordance with API RP 6HT (DNV-GL-RP-0034 Section 3.1.4.2). All heat treatment furnaces are computer controlled and calibrated according to API 6A Annex M/ASTM A991.

Furnace dimensions 4m x 2m x 1.2m (L x W x H). All furnaces are equipped with contact thermocouples connected to the computer with associated thermal treatment graphs. The control system is in line with DNV-GL-RP-0034/API RP 6HT.

Table 3

Thermal treatment parameters

ITEM	NR. OF HEAT TREAT. BATCHES	NORMALIZING		AUSTENIZATION		TEMPERING	
		TEMP	HOLDING TIME (HOURS)	TEMP	HOLDING TIME (HOURS)	TEMP	HOLDING TIME (HOURS)
1	1	890^{o}C	min. 1 hrs.	860 ^{o}C	min. 1 hrs.	685-690 ^{o}C	min. 2 hrs.
2	1	890^{oC}	min. 1 hrs.	860 ^{o}C	min. 1 hrs.	685-690 ^{o}C	min. 2 hrs.

All parts will be loaded in a single row with about 50 mm between them. The furnace orientation is horizontal. The furnace loading method is in accordance with DNV-GL specifications and the sacrificial sample will be placed in the center of the furnace. Thermal treatment parameters are highlighted in Table 4.

The maintenance time (at least 1 h) at 890°C starts when the contact thermocouple recorder indicates 890°C.

In the thermal treatment furnace, there are: temperature monitoring systems, ventilation systems (turbines), time control and a cooling liquid recirculation system [13;17].

Transferring the parts from the thermal treatment furnace to the cooling trough is done within 60 seconds.

Thermal treatment parameters:

1. Normalization:

- loading temperature: <750^{o} C
- heating speed: 100-200 ^{o} C/ hour
- maintaining at austenitization temperature 890 ^{o} C min. 1 hour / contact thermocouple

- cooling in the air

2. Austenitization

- loading temperature: <750^{o} C
- heating speed: 100-200 ^{o} C / hour
- maintaining at austenitization temperature 860 ^{o} C min. 1 hour / contact thermocouple
- cooling in water
- water temperature is max. 20 ^{o} C
- the surface temperature of the parts at the completion of the treatment approx. 50 ^{o} C

3. Tempering

- loading temperature: <550^{o} C
- heating speed: 100-200 ^{o} C/ hour
- maintaining at austenitization temperature 685-690 ^{o} C min. 2 hours / contact thermocouple
- cooling in the air.

The entire heat treatment cycle according to API RP 6HT by using contact thermocouples, at the critical treatment points, will be at least 60 minutes and at least 120 minutes on the recovery treatment.

A special simulation treatment under certain extreme conditions sometimes of use of the piece or to highlight certain mechanical features in our case SPWHT will be:

- heating at 650 ^{o} C maintaining 2.5 hours minimum and maximum 5 hours (at a heating temperature of approx. 150 ^{o} C / hour).

3. Conclusions

In this paper we have analyzed the conditions and stages that a forged semi-finished product must meet in order to be accredited under the requirements of the DNVGL-ST-F101 standard. Both the forging technique and the types of thermal treatment applied are important to meet the requirements of the assessment standard and to offer the possibility of issuing an internationally recognized 3.2 certificate.

The main conclusions can be summarized as follows:

- The DNV-GL-ST-F101 standard is important and widely used in the metallurgical field, especially in the field of forged semi-finished products for the extractive, natural gas, oil, maritime industry, etc.
- The procedure for issuing an internationally recognized material certificate DNV-GL type 3.2 requires the fulfillment of essential criteria both in forging and thermal treatment areas;

- Forging materials involves obtaining forged semi-finished products in several successive stages and with a certain minimum degree of deformation accepted;

- The thermal treatment applied is carried out in several successive stages and is controlled by contact thermocouples;

- Compulsory proof - sacrification of a forged piece - is placed in the center of the thermal treatment charge. The charge will be done on a single row.

- All mechanical testing including those obtained after SPWHT are indicated in the product quality certificate.

*SPWHT-Simulated post-weld heat treatment.

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