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GUIDELINES ON
HULL STRUCTURE OF THERMOPLASTIC VESSELS (PROVISIONAL)

JULY 2021

Guidelines on

Hull Structure of Thermoplastic Vessels
(Provisional)
July 2021

Contents

Sections

Section 1

General

1.1 Scope and Applicability

1.1.1 These guidelines have been developed to provide requirements regarding the use of polyethylene as a structural material for hull structure of vessels in inland waters. The guidelines cover requirements related to material properties, structural design and manufacture of such vessels.

1.1.2 These guidelines are intended for use in certification of vessels built to polyethylene materials like Low Density Polyethylene (**LDPE**), Medium Density Polyethylene (**MDPE**) and High Density Polyethylene (**HDPE**). Other types of plastics such as Linear Low Density Polyethylene (LLDPE), Cross-linked Polyethylene (XLPE), Ultra High Molecular Weight Polyethylene (UHMW) etc., may be specially considered depending upon their suitability for the intended application.

1.1.3 Vessels built in compliance with these Guidelines may be assigned additional notations such as **LDPE**, **MDPE** and **HDPE** depending upon the material used for the construction.

1.1.4 LDPE is flexible and tough, easy to process and has excellent chemical resistance. MDPE has better mechanical properties than LDPE as well as higher stiffness, excellent low temperature impact strength and excellent environmental stress crack resistance. HDPE is the stiffest of the polyethylene family. HPDE has excellent chemical resistance and good processability. It is preferred that HDPE be used for vessel materials because of the high impact resistance and better longevity.

1.1.5 These guidelines address only the hull structure and its manufacture. For other aspects not covered by these guidelines, the relevant requirements of the IRS *Rules for Construction and Classification of Inland Waterways Vessels* are to be complied with, as applicable.

1.1.6 The certification aims at providing an appropriate safety level for the vessels, their intended application and design limitations. The technical and safety standards prescribed are considered adequate for such vessels with overall lengths in the approximate range 6 to 24 m and with speeds up to 45 knots. Certification of vessels with lengths other than those indicated above may be specially considered.

Section 2

Material Properties

2.1 General Requirements

2.1.1 Approval is accorded to the manufacturer who produces the raw material at the final stage before vessel production:

2.1.1.1 For rotational moulding, the approval is granted to the granulate/ powder manufacturer.

2.1.1.2 For thermoforming of sheets the approval is granted to the sheet manufacturer.

2.1.2 Ageing properties are to be verified on sheet material with pigments etc. which is to be used in the production.

2.1.3 The content of pigments is not to exceed 4% and is to be evenly distributed in the material. Any detrimental effect on the strength of the material is to be recorded.

2.1.4 The impact strength of the material at low temperatures is to be approved in relation to the fracture character at pendulum notch impact testing.

2.1.4.1 Brittle fracture at temperatures above 0°C is not acceptable.

2.1.4.2 If the transition between tough and brittle fracture occurs between 0°C and -20°C, the following statement is entered on the vessel's certificate:

> *"The impact strength of the plastic material is reduced at low temperatures. The vessel is not recommended to be used in cold temperatures."*

2.1.5 The ability of the material to withstand heating by sunlight is subject to approval on the basis of the reduction in the material stiffness between 20°C and 65°C.

2.1.6 A reduction in the shear modulus of the material greater than 80% due to heating is not acceptable.

2.1.6.1 If the reduction is between 30% and 80%, the following statement is entered on the vessel's certificate:

> *"The material softens at high temperatures and may be permanently deformed by long term loading at high temperatures."*

2.1.7 It is recommended that flame resistance of polyethylene plastics may be increased by adding flame retardants. Commercially available flame retardants contain mainly bromine, chlorine, phosphorus and nitrogen or aluminum and magnesium hydroxides which are incorporated into the polymers during their processing. Aluminium tri-hydroxide may be used when the processing temperature is below 200°C. When processing temperatures are above 200°C. Magnesium di-hydroxide may be used. The fire retardant additives used are to be indicated by the manufacturer.

2.1.8 Engines spaces, if arranged, are to be provided with fire protection of minimum 15 minutes rating, Arrangement and materials for structural fire protection are to be approved. The fire protection is to cover the entire boundary of the engine space above lowest waterline.

2.1.9 For small vessels (normally L < 15 m) arrangements other than those specified in 2.1.8 would be specially considered (e.g. intumescing paint, fire retarding resin on interior surface of laminates).

2.2 Documentation

2.2.1 The material properties and documentation requirements for **LDPE** and **MDPE** are indicated in Table 2.2.1 (a) and (b). Similarly Table 2.2.1 (c) specifies the requirements for **HDPE**.

2.2.2 The test specimens are to be taken from the material which is used in production, but the material is not to be weakened due to the manufacturing process.

2.2.3 The approval is to state the manufacturing process for which the material is approved.

Table 2.2.1 (a): Properties and documentation for LDPE and MDPE

Properties	***Test method***	***Results to be given for information except where noted.*** **** Also required by delivery***
Tensile properties	ISO 527-2:2012 (Test specimen type 2, 5 - 50 mm/min.)	Curve at 20°C and 65°C
Shear modulus	ISO 6721-2:2019 (torsion pendulum)	Curve for temperature range 20°C to 65°C
Shear strength	ASTM D792-20	
Creep	ISO 899-1:2017 (carried out on at least 3 stress levels and 2 test pieces per level)	Isochronous stress-deformation diagram for 1000,100, 10, 1 and 0.1 hours at 20°C and 65°C
Fatigue	Fatigue test carried out with constant stress or deformation amplitude	Curves up to at least 100.000 loading cycles at 20°C
Hardness	ISO 868:2003 (Shore D)	Given at 20°C, read after 15 seconds
Falling weight impact	ASTM D5628-18 (method A). The radius of the drop hammer's striking surface is to be 12.5 mm	Fracture energy by visible crack as fracture criterion, given at 0°C and at 20°C and with relevant material thickness
Pendulum impact	With V-notch 45° in accordance with ISO 180:2019. For particularly flexible materials an alternative test method (tensile impact strength) may be used.	Fracture energy at 0°C as well as a description of fracture type. The notch impact strength is only stated for non-aged
Ageing	ISO 179-1:2010 (Charpy) without notch: Natural ageing DIN 53386, item 6.1. Accelerated ageing: DIN 53387	Plotted fracture energy for aged materials as a function of logarithmic time. The time is normally to cover 48 months natural ageing or 5 000 hours accelerated ageing. A shorter time can be approved if the ageing process is clarified at an earlier stage
Fuel resistance	Stressed material submerged in normal engine fuel	Description of surface cracking
Melt index	ISO 1133-1:2011	To be given for polyethylene
Chemical resistance	ISO 175:2010	List of chemicals which may damage the material
Density	ISO 1183-2:2019	To be given for polyethylene *
Oxygen index	ASTM D2863-19/ ISO 4589-2:2017	Value *
Flexural Properties	ASTM D790-17/ ISO 178:2019	
Compressive strength	ASTM D695-15/ ISO 604:2002	

Table 2.2.1 (b): Properties of LDPE and MDPE				
Property	***Requirement LDPE***	***Requirement MDPE***	***Unit***	***Comments***
Density	< 0.930	0.930 - 0.945	g/cm^3	
Melt index	Stated value ±1.0 Though max. 3.5	Same as LDPE	g/10 min.	
Tensile yield stress	min. 7.5 min. 4.5	min 13.0 min 8.0	N/mm^2 N/mm^2	At 20 At 65°C
Elasticity modulus in tensile yield	min. 180	min. 350	N/mm^2	At 20°C
Tensile creep strength	max. 2.5 at stress 2.0	2.0 at stress 3.0	% N/mm^2	Deformation after 100 hours at 20°C
Flexural Strength	8-15	20	N/mm^2	
Flexural Modulus	250	500	N/mm^2	
Compressive Strength	9.6	15	N/mm^2	
Shear Strength	8	12	N/mm^2	
Hardness	Stated value ±3	Same as LDPE	Shore D	Tested at 20°C and read after 15 sec.
Impact strength (drop test without notch)	min. 15	min. 15	J/mm thickness	Freely supported test piece 0°C
Notch impact strength (pendulum test with notch)	No brittle fracture	No brittle fracture	Visual	Required only for vessels with single skins 0°C
Pore contents	max. 15 max. 20	Same as LDPE Same as LDPE	% of thickness % of thickness	In structural parts In the vessel elsewhere
Impact tensile strength of aged material	No brittle fracture min. fracture energy 1.0 J/cm^3	Same as LDPE J/cm^2	Visual	Aged material corresponding to 4 years of natural ageing, tested at 0°C and with a test speed 2 x 10^5 %/mm

Table 2.2.1 (c) : Properties of HDPE			
Property	**Properties of HDPE**	**Unit**	**Test Method**
Density	0.946 to 0.972	g/cm^3	ASTM D792-20
Melt Mass Flow Rate	0.030 to 10 (190°C/2.16 kg)	g/10 min	ISO 1133-1:2011
Tensile Yield Stress	min 17	N/mm^2	ASTM D638-14
Ultimate Tensile Stress	min 24	N/mm^2	ASTM D638-14
Tensile Elongation at Yield	1.0 to 27	%	ASTM D638-14
Tensile Elongation at Break	10 to 1500	%	ASTM D638-14
Tensile Creep Modulus	292 (After 1000 hrs)	N/mm^2	ISO 899-1:2017
Compressive Stress	20	N/mm^2	ASTM D695-15/ ISO 604:2002
Shear Strength	18	N/mm^2	ASTM D792-20
Flexural Strength	40	N/mm^2	ASTM D790-17/ ISO 178:2019
Flexural Modulus	750	N/mm^2	ASTM D790-17/ ISO 178:2019
Hardness	as LDPE **(1)**	Shore D	
Impact strength (drop test without notch)	as LDPE **(1)**	J/mm thickness	
Notch impact strength (pendulum test with notch)	as LDPE **(1)**	Visual	
Pore contents	as LDPE **(1)**	% of thickness	
Impact tensile strength of aged material	as LDPE **(1)**	Visual	
Viscosity Number (Reduced Viscosity)	157.8 to 398.3	ml/g	ISO 1628-3:2010
Water Absorption	0.010 to 0.017 % (24 hrs)		ASTM D570-98/ ISO 62:2008

(1) *Test method, results and comments of referred material are to be applied as indicated in Tables 2.2.1 (a) and 2.2.1(b).*

Note: *The information contained at the table above stated at 23 °C are typical values intended for reference and comparison purposes only. Above mentioned values to be used for design calculations are also to be agreed by IRS.*

Section 3

Structural Design

3.1 General

3.1.1 Material properties are given in the tables for scantling calculation purposes as a reference. Those properties are to be validated by material test results.

3.1.2 The design of the vessel is to be suitable for the manufacturing process and the raw material being used.

3.1.3 When forming vessels of polyethylene, it is to be taken into consideration that the mechanical properties of the material vary with the temperature and the duration of the loading.

3.1.4 Hard points in the structure are as far as practicable to be avoided. Stiffening is to be evenly distributed over the hull, to the extent this is practicable.

3.1.5 The design is to be such that sufficient hull stiffness is obtained. Large flat surfaces are to be avoided as far as practicable.

3.2 Rule thickness

3.2.1 Rule thickness is the value stated in 3.3.2.

3.2.2 A measured thickness is regarded as satisfactory when the average of the values measured at 20 points is not less than the rule thickness and if none of the values measured at the individual points is more than 15% below rule thickness.

3.2.3 Local reinforcements that are welded or glued to the hull, may be specially considered as part of the skin thickness.

3.3 Scantlings

3.3.1 Scantling values obtained by direct calculation methods are not to be less than 80% of those stated in relevant empirical formula given below.

3.3.2 Hull Thickness

3.3.2.1The thickness of the outer hull bottom and side is not to be less than:

$$t = k\,s\sqrt{\frac{P_F}{6.7L}}(14 + 3.6L)$$

Where:

	LDPE	MDPE	HDPE
k	1	0.85	0.72

s = stiffener spacing in metres
P_F = Pressure factor for bottom or side (P_{Fb} or P_{FS}), as taken from the Tables 3.3.2.1 (a) and (b) below:

Table 3.3.2.1 (a) : Values for P_{Fb}								
V [knots]	Length [m]							
	3	6	9	12	15	18	21	24
10	18	28	40	54	70	85	98	110
15	25	38	50	65	80	95	109	120
20	37	51	66	82	97	112	125	138
25	52	69	87	104	120	134	150	163
30	70	91	112	131	150	165	182	197
35	93	119	142	166	185	202	220	238
40	120	150	179	205	227	248	268	287
45	150	185	219	251	275	298	320	342

Table 3.3.2.1 (b) : Values for P_{Fs}								
V [knots]	Length [m]							
	3	6	9	12	15	18	21	24
10	17	25	37	54	71	89	109	129
15	17	26	38	55	72	90	110	130
20	19	28	40	57	74	92	113	133
25	21	30	43	60	77	97	118	138
30	26	36	48	66	83	102	124	144
35	32	42	56	72	90	109	131	151
40	40	51	63	80	98	118	140	160
45	50	61	73	90	108	128	150	171

3.3.2.2 The thickness of the inner hull is not to be less than:

$$t_i = 0.8\ t\ [mm]$$

3.3.2.3 It is recommended that rotation moulded vessels are to have a hull weight of at least k x 45 kg. The vessel is to be stiffened in such a manner that keel, bottom or side shell is not deformed by normal load.

3.3.2.4 Proper stiffness is to be provided and demonstrated to IRS. For this purpose direct calculation methods may be utilized.

3.3.2.5 Scantlings of stiffeners are to be adequate with intended service of the vessel and to withstand loads to which the vessel may encounter. For this purpose direct calculations are to be submitted to IRS along with plans. The scantlings of primary and secondary stiffening members are to be determined by direct calculation where the vessel is of unusual design, form or proportions.

3.3.2.6 Transom for engine mounting is normally to be stiffened over its full breadth. Scantlings based on practical testing with simulated loads from the engine may be accepted.

Section 4

Manufacture

4.1 General

4.1.1 Premises

4.1.1.1 Premises for manufacturing of vessels of polyethylene are to be suitable for the production process applied.

4.1.1.2 Such vessels can be manufactured either by rotational moulding or welding.

4.1.1.2 Uncontrollable draughts are to be avoided in the vicinity of the production machinery and in cooling rooms.

4.1.1.3 Premises and production machinery are to be arranged to avoid risk of pollution by oil spill, dust etc.

4.1.2 Marking of produced vessels

4.1.2.1 The vessel is to have a durably fitted plate or similar which clearly states the structural material of the vessel.

4.1.2.2 The vessel manufacturer is to supply the following with each vessel:

- information on the vessel's presupposed use,
- directions for maintenance and repair as well as information on substances which may have detrimental effects on the vessel's structural material.

4.2 Rotation Moulding

4.2.1 General

4.2.1.1 In rotational moulding, rigid, resilient hollow bodies are formed by powdered plastic material in heated molds, which are rotated simultaneously in two planes perpendicular to each other. The plastic particles make contact and melt on the inner surfaces of the hot molds and fuse in layers until all the powder is fused and the desired end product and wall thickness is obtained. The wall thickness is controlled by the amount of powder placed in the mold. Rotationally molded pieces are stress-free except for slight shrinkage forces because the pieces are produced without any external pressure. Additionally, there is practically no scrap in rotational molding.

4.2.1.2 Raw materials may be approved in accordance with Section 2. No materials built into the vessel are to have detrimental effects on the other materials applied.

4.2.1.3 If the vessel manufacturer is to grind granulate to powder, the grinding and sieving equipment are first to be approved by IRS.

4.2.1.4 A pigment of approved type and in the approved quantity is to be added to the powder. During or after the grinding the powder is to be sifted through a mesh of not more than 800 microns.

4.2.1.5 Material moulded in accordance with the vessel manufacturer’s procedure is to at least have properties as given in Table 2.2.1(a) and Table 2.2.1(b) or Table 2.2.1(c).

4.2.1.6 The skins in double hulled constructions and in sandwich constructions are to be watertight. Screws or bushings in the skins are also to be watertight.

4.2.1.7 Where exposed, the connection between inner and outer skin is to be watertight.

4.2.1.8 Requirements to moulding time, temperatures and cooling time are to be determined based on quantity of powder used and the rotation speed, on the background of inspection of complete moulded vessels.

4.2.2 Moulding condition

4.2.2 1 Release compositions applied to the mould are not to have any detrimental effects on the vessel material, e.g. stress cracking.

4.2.2.2 Regenerated raw material will not be accepted for use in hulls manufactured by rotation moulding.

4.2.2.3 The rotation procedure is to be the same for moulding of all vessels of the same type.

4.2.2.4 The weight quantity of powder in the mould is not to be less than 1% below the specified value.

4.2.2.5 The temperature is to be automatically controlled. The temperature and its specified permissible variations will be subject to approval in each case, on the basis of the limitations of the raw material properties. The temperature at each measuring point is not to vary by more than +5°C for each moulding process.

4.2.2.6 The sintering time and the after-sintering time is stipulated on the basis of thickness measurements on the vessel type in question to ensure that an even distribution of material in the mould is obtained. The process time is not to vary by more than + 1 minute from the approved time. Any welding together of inner and outer mould is to be approved in each separate case.

4.2.2.7 The cooling-down process is to be the same for each vessel of the same type, and is to be stipulated on the basis of the sintering temperature, vessel type and raw material, so that deformations in the material are avoided.

4.2.2.8 If alterations are made in the manufacturing method, IRS is to be informed for considering whether special tests will be required to check the material quality.

4.2.3 Moulded vessels

4.2.3.1 The material in the finished moulded vessels is to be without any visible surface flaws which might be of significance to the vessel's service. Surfaces and cross sections are not to show any sign of either insufficient fusion of the powder particles or thermal degradation of the material.

4.2.3.2 Pores or air bubbles must not be so numerous or of such size that the material properties are significantly reduced. The amount and size allowed are to be stipulated for each type of material.

4.2.3.3 The material in the moulded vessels is to comply with the requirements to minimum mechanical properties specified for the raw material in question.

4.2.3.4 Completed vessels are not to have significant deformations, and all welded joints are to be tight.

4.2.4 Internal quality control

4.2.4.1 The raw material is to be stored in accordance with the manufacturer's instructions. The vessel manufacturer is to keep a verifiable record of the raw material supplier's certificate data, and store samples from each material delivery.

4.2.4.2 The vessel manufacturer is to record the following process data for each individual vessel:

- weighed quantity of powder
- temperature
- sintering and after-sintering time
- cooling-down time.

4.2.4.3 Each vessel is also to be visually checked for surface flaws and tightness of welded joints.

4.2.4.4 Each vessel is to be marked with its production number, which is to identify the mould in which the vessel has been manufactured. The marking is to be made in a durable manner.

4.2.4.5 Thickness measurements are normally to be carried out on vessels that are cut into several sections. Such measurements are to be carried out on one out of 200 vessels manufactured in each mould.

4.2.5 Production Surveillance

4.2.5.1 Moulding time, temperature, density and melt index of the materials are to be recorded.

4.2.5.2 The inner surfaces and weldments are to be visually inspected and the hull thicknesses measured by cutting various sections of the vessel.

4.3 Welding

4.3.1 General

4.3.1.1 There are various methods by which plastics can be welded for fabrication of different items. Among others, these include extrusion welding and hot gas welding, which are generally used for manufacture of vessels.

4.3.1.2 Definitions

.1 *Extrusion welding* – A process in which a welding rod is drawn into a miniature hand held plastic extruder, plasticized, and forced out of the extruder against the parts being joined, which are softened with a jet of hot air to allow bonding to take place. It is the preferred technique for joining material over 6 mm thick.

.2 *Hot gas welding*, also known as hot air welding, is a plastic welding technique, which is analogous to metals, though the specific techniques are different. A specially designed heat gun, called a hot air welder, produces a jet of hot air that softens both the parts to be joined and a plastic filler rod, all of which must be of the same or a very similar plastic. Two sheets of plastic are heated via a hot gas or a heating element and then rolled together. This is a quick welding process and can be performed continuously.

4.3.2 Equipment

4.3.2.1 Equipment used for hot gas welding and extrusion welding are generally in accordance with national / international standards such as EN 13705:2004.

4.3.3 Internal quality control

4.3.3.1 Raw materials may be approved in accordance with Section 2. No materials built into the vessel are to have detrimental effects on the other materials applied.

4.3.3.2 The vessel manufacturer is to keep a verifiable record of the raw material supplier's certificate data, and store samples from each material delivery. The raw material is to be stored in accordance with the manufacturer's instructions.

4.3.3.3 Vessels manufactured by welding processes are to also comply with the requirements in 4.2.4.3 to 4.2.4.5

4.3.3.4 Welding Procedure Specification (WPS) and Non-Destructive Testing (NDT)

.1 The welding procedure specification (WPS) is to be prepared and non-destructive testing (NDT) of weld joints is to be carried out in accordance with recognized national/ international standards. Similarly, welders for thermoplastics are also to be trained and qualified as per recognized national/ international standards. An indicative list of standards for welding of thermoplastics is provided in Table 4.3.3.

Table 4.3.3 : Standards related to thermoplastics		
S No	Standard No	Standard
1	ISO 472:2013 Amd 1 - 2018	Plastics – Vocabulary
2	ISO 17855-1:2014	Plastics – Polyethylene (PE) Moulding and Extrusion Materials Part 1: Designation System and basis for specifications.
3	ISO 17855-2:2016	Plastics – Polyethylene (PE) Moulding and Extrusion Materials Part 2: Preparation of test specimens and determination of properties
4	ISO 14632:1998	Extruded sheets of polyethylene (PE-HD) - Requirements and test methods
5	ISO 15527:2018	Plastics - Compression-moulded sheets of polyethylene (PE-UHMW, PE-HD) - Requirements and test methods.
6	ISO 20753:2018	Plastics – Test Specimens
7	ISO 11469:2016	Plastics - Generic identification and marking of plastics products
8	ISO 11501:1995	Plastics - Film and sheeting - Determination of dimensional change on heating
9	EN 13705: 004	Machines and equipment for hot gas welding (including extrusion welding)
10	EN 13067:2013-01	Plastics Welding Personnel – Qualification testing of Welders – Thermoplastic welded assemblies
11	PD CEN/TS 16892:2015	Plastics – Welding of thermoplastics – specifications of welding procedures.
12	EN 12943:1999	Filler Materials for Thermoplastics
13	ISO 16012:2015	Plastics - Determination of linear dimensions of test specimens
14	EN 12814-1:1999	Testing of Welded Joints of Thermoplastics Semi-finished Products Part 1 – Bend Test
15	EN 12814-2:2000	Testing of Welded Joints of Thermoplastics Semi-finished Products Part 2 – Tensile Test
16	EN 12814-3:2014	Testing of welded joints in thermoplastics semi-finished products - Part 3: Tensile creep test
17	EN 12814-4:2018	Testing of welded joints of thermoplastics semi-finished products - Part 4: Peel test
18	EN 12814-5:2000	Testing of Welded Joints of Thermoplastics Semi-finished Products Part 5 – Macroscopic Examination
19	EN 12814-6:2000	Testing of welded joints of thermoplastics semi-finished products - Part 6: Low temperature tensile test
20	EN 12814-7:2002	Testing of welded joints of thermoplastics semi-finished products - Part 7: Tensile test with waisted test specimens
21	EN 12814-8:2001	Testing of Welded Joints of Thermoplastics Semi-finished Products Part 8 – Requirements
22	EN 13100-1:2017	Non-destructive Testing of Welded Joints of Thermoplastics semi-finished products – Part 1: Visual Examination
23	EN 13100-2:2017	Non-destructive Testing of Welded Joints of Thermoplastics semi-finished products – Part 2: X Ray Radiographic Testing
24	EN 13100-3:2005	Non-destructive Testing of Welded Joints of Thermoplastics semi-finished products – Part 3: Ultrasonic Testing
25	EN 13100-4:2012	Non-destructive testing of welded joints of thermoplastics semi-finished products - Part 4: High voltage testing
26	EN 14728:2019	Imperfections in Thermoplastic Welds- Classification
27	EN 16296:2012	Imperfections in thermoplastics welded joints - Quality levels

End of the Guidelines