C68-11.3.2.3

IALA GUIDELINE

G1006

PLASTIC BUOYS

Edition 4

December 2018

10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01- Fax +33 (0)1 34 51 82 05 - contact@iala-aism.org
www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

DOCUMENT HISTORY

Revisions to this IALA document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
December 1997	1st issue	Council 18
December 2005	Entire Document Reformatted to reflect IALA documentation hierarchy	Council 35
May 2008	Entire document Review and update at IALA Floating aids 2008 workshop and EEP11/12	Council 43
December 2013	Pages 4,6,7,8 and 9 References to GUIDELINE 1040 deleted and replaced by IALA GUIDELINE “1077 Maintenance of Aids to Navigation”	Council 56
December 2018	All pages, all sections Complete revision and update of the document	Council 68

CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

List of Tables

CONTENTS

List of Figures

CONTENTS

CONTENTS

1. INTRODUCTION

A plastic buoy may be defined as a floating aid with at least the buoy hull constructed of a plastic material. Plastic buoys have been in production and use since the 1980's.

Plastic buoys are commercially available in a wide variety of sizes and shapes, from small one-piece buoys with a diameter of 0.16 m to very large modular buoys with diameters of 4 m. Plastic buoys can be classified as unitary (one-piece) buoys or modular (multiple component) buoys.

They are produced mainly from polyethylene materials in different designs.

2. SCOPE

This guideline has been developed to assist marine aids to navigation (AtoN) manufacturers and authorities when developing and selecting plastic buoys for different purposes. It also provides information about plastic material types, manufacturing techniques, quality control considerations, and standard test procedures commonly in use.

3. POINTS TO BE CONSIDERED WHEN EVALUATING PLASTIC BUOYS

3.1. OPERATIONAL PERFORMANCE

Due to the lower material density of plastic when compared to steel, plastic buoys are typically significantly lighter than steel buoys. Lightweight buoys require careful design to avoid a rapid rolling or pitching motion which will detract from their operational effectiveness in waves, wind and current.

The operational performance of a plastic buoy should be stated for different environmental conditions to permit the selection of the correct buoy design. There are many different designs of plastic buoys available to accommodate a variety of environmental conditions.

The use of a hydrostatic study for the plastic buoy by an accredited Naval Architect can assist in the buoy selection process. Please refer to IALA Guideline G1099 on the Hydrostatic design of buoys.

3.2. LIFE CYCLE COST COMPARISON

Plastic buoys typically have a shorter design life than steel buoys and require replacement earlier than steel buoys. Factors that directly affect the anticipated design life of a plastic buoy are the degradation of plastic strength and the fading of the colour.

The purchase cost of plastic buoys is dependent on the construction technology. Plastic buoys can have lower ongoing maintenance costs through the elimination of sand-blasting and painting costs as well as reductions in vessel, personnel, mooring and transportation costs. Sea-based maintenance can be achieved on most plastic buoys, including jet spray washing and other normal service tasks. Various maintenance procedures are suitable for different plastic materials. More guidance is available in IALA Guideline G1077 Maintenance of Aids to Navigation.

ANNEX A presents the advantages and disadvantages of plastic buoys.

The use of plastic buoys to replace legacy steel buoys is typically warranted when lower overall life cycle costs can be achieved while also meeting the operational performance requirements as a marine Aid to Navigation.

For further information see also IALA Guideline G1047 Cost Comparison Methodology of Buoy Technologies.

3.3. PLASTIC MATERIAL TYPES

The required strength of a buoy plastic hull is dictated by the operational environment (sheltered, exposed, ice, etc.) and buoy handling operations. Different plastic materials are available for use in the manufacturing of plastic buoys and each type has different properties which provide different performance characteristics. Some plastic materials may offer better resistance to marine fouling than others. Plastic buoys should be sufficiently robust to withstand fouling being scraped off, or water jet spraying, regularly throughout the working life of the buoy.

For plastic buoys, the following plastic materials are primarily used:

- polyethylene (PE);
- glass reinforced plastic (GRP);
- polyurethane / elastomer coated foam;
- ionomer foam.

Polyethylene is the most common plastic used for the manufacturing of plastic buoys. Therefore this guideline mainly deals with polyethylene plastic buoys (chapter 4).

3.4. CHANGE IN MATERIAL PROPERTIES OF PLASTICS DURING DESIGN LIFE

Degradation of plastics due to ultraviolet (UV) light must be considered. The type of plastic material selected and the addition of UV inhibitors used to protect the plastic will impact the design life. Degradation of the plastic due to UV causes the plastic to become more brittle and this loss of ductility reduces the impact strength of the plastic during the design life. The amount of exposure to UV in the operating environment must be considered, degradation of plastic strength and loss of ductility is accelerated in latitudes with greater exposure to UV energy.

At latitudes with higher UV exposure and higher temperatures, the loss of strength occurs faster than at latitudes with lower UV exposure.

The rate of degradation varies based on the type of plastic selected and the addition of UV inhibitors or UV stabilisers to protect the mechanical properties of the plastic. Buoy manufacturers should provide rapid weathering tests of the plastic material to prove their predicted long-term stability of the mechanical properties with respect to UV radiation. Test standards could be:

- ASTM G155 Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials;
- ISO 4582: 2017 Plastics - determination of changes in colour and variations in properties after exposure to glass-filtered solar radiation, natural weathering or laboratory radiation sources;
- ISO 4892 (1-4) Plastics - methods of exposure to laboratory light sources.

3.5. CHANGE IN COLOUR OF PLASTICS DURING DESIGN LIFE

3.5.1. GENERAL

Colour fading due to UV radiation is to be expected. The fade resistance of the colour pigment used to colour the base plastic resin will determine the length of time the colour will be compliant with IALA

Recommendation R0108 (E-108) – Surface Colours Used as Visual Signals on Marine Aids to Navigation and the IALA Guideline G1134 Surface Colours used as Visual Signals on AtoN.

The performance of the pigment system is a crucial factor in determining the anticipated useful life of any plastic components. Colour fading will occur more rapidly in latitudes with greater UV radiation.

It is a common misperception that UV inhibitors and stabilisers are added to protect against the fading of colour. These additives are used to slow the rate of degradation of the mechanical properties of the plastic and not to prevent colour fading.

Colour pigments used for all plastics should be of the highest quality suitable for marine use and UV exposure.

Buoy manufacturers should provide rapid weathering tests of the plastic material to prove their predicted rate of colour fading with respect to UV radiation during the design life.

3.5.2. WAYS TO ASSESS THE EXPECTED LIFETIME OF THE COLOUR

A common industry practice to measure colour fading is to use accelerated UV weathering in a Xenon Weatherometer in accordance with appropriate standards completed by a third party accredited test laboratory. Test standards could be:

- ISO 4892 (1-4) Plastics - methods of exposure to laboratory light sources;
- EN 16472 Plastics - method for artificial accelerated photo ageing using medium pressure mercury vapour lamps;
- ASTM D2244 - 16 Standard practice for calculation of colour tolerances and colour differences from instrumentally measured colour coordinates;
- ASTM D2565 - 16 Standard Practice for Xenon Arc Exposure of Plastics Intended for Outdoor Applications;
- ISO 1664-4 Colorimetric evaluation of colour coordinates and colour differences according to the approximately uniform CIELAB colour space.

3.6. TRANSMISSION OF FORCES AND SAFE WORKING LOAD

Due to the lower tensile strength of plastic when compared to steel, the transmission of lifting and mooring loads requires careful consideration. While mooring loads are typically well distributed throughout the plastic hull during operation, additional loads are imposed during buoy deployment and retrieval.

Most buoys will have both a lifting eye and a mooring eye. Depending on the buoy design, the lifting eye and the mooring eye can be designed as follows:

- Integrated as part of the plastic hull;
- A galvanized/coated steel or stainless steel structure for attachment of the hull floats and super structure.

The transmission of forces between the mooring point and lifting point is critical in the safe handling of plastic buoys. The operational conditions for buoy deployment and retrieval must be considered as sea state and current can result in dynamic loads in lifting of the buoy.

Buoy manufacturers should clearly identify the design of force transmission and the design factors used to specify safe working load.

3.7. METAL PARTS

A common plastic buoy may include the following metal parts:

- lifting eye(s);
- mooring eye(s);
- standard parts (fasteners);
- inserts;
- ballast (in the case of cast iron or steel).

The metal parts of a buoy should be selected in such way that no galvanic corrosion is produced when joining different materials. Sometimes it is necessary to insulate metal parts (paint, insulating hull, bitumen coat).

Because of the mooring eye wear an appropriate reserve is required which depends on the maintenance intervals. With measurements made during the maintenance process, the wear can be determined. The mooring eye should be replaceable in case of wear.

3.7.1. STANDARD PARTS

It is highly desirable to use non-corrosive standard parts, for example from hot-dipped galvanized steel, marine-grade aluminium, marine grade stainless steel or brass.

3.7.2. METALLIC INSERTS

Metallic inserts are used for fastening items to the buoy such as the lantern, lettering, daymarks, etc. They can be made from the materials mentioned in section 3.7.1.

In the manufacturing process, care should be taken to ensure that threaded inserts are fixed and aligned correctly in the material, otherwise they should be avoided.

Care should be taken and the right amount of torque should be used when securing fasteners into threaded inserts to avoid detachment or pull-out from the buoy body.

3.7.3. BUOY BALLAST

Ballast is often used to achieve buoy stability. An adjustable ballast weight system provides the ability to optimise performance for a variety of operational and environmental conditions.

If the ballast is permanently mounted inside the buoy, it must be secured in place so that no movement is possible.

3.8. RADAR VISIBILITY

Plastic buoys require the use of a passive radar reflector to be visible to radar. Additional information is available in the IALA NAVGUIDE and section 8.3 below.

3.9. STATIC ELECTRICAL CHARGE BUILD-UP

It may be necessary to incorporate a grounding strap on plastic buoys to prevent the build-up of static electricity which may cause shock or damage to electronic equipment.

3.10. LETTERING METHODS

Most administrations apply the position name/number on the buoy body. Solutions for long-term stability of the lettering should be explored. Possible solutions can be (not applicable on all buoy types):

Figure 2: Painting

Figure 3: Painting

Figure 4: Adhesive foil


Figure 6: Mounted plates

- Painting (Figure 2, Figure 3)
- Application of adhesive foils (Figure 4)
- Mounted plates (welded or fixed by screws, Figure 6)
- Engraving (Figure 7)
- Plastic spray method (Figure 1)
- Mould-In-Graphic (only for long term use of the buoy on the same position, Figure 5)


Figure 1: Plastic spray method

Figure 5: Mould-In-Graphic


Figure 7: Engraving

3.11. DESIGN REQUIREMENTS FOR USE OF PLASTIC BUOYS IN ICE BUILT UP AREAS

A year-round use of plastic buoys can save money as winter work and using fleet or contractors to retrieve buoys can be reduced. Some plastic buoys, especially spar and conical shaped buoys are suitable for ice conditions. These can be:

- Ice floes in current or moving ice fields;
- The buoy is frozen in a solid ice field.

The impacts on the buoy can be abrasion, cutting, compression effects, tension and bending.

To withstand these conditions, the buoy hull material must be sufficiently robust and its shape must be constructed accordingly.

3.11.1. BUOY HULL

The main reason for ice damage to buoys is insufficient strength in the buoy hull. This may be due to insufficient wall thickness or abrasion because of wrong selection of plastic material type. Changes in wall thickness also present stress concentration points at the transition of thickness area and therefore wall thickness should be consistent.

3.11.2. BUOY SHAPE

The buoy should be strong enough to go under the ice and survive until the ice floe has moved away. The buoy shape, strength, lifting and mooring points should be constructed accordingly. The size of the lifting eyes frequently requires a compromise between minimum size for ease of handling and reducing the points for ice accretion.

When possible, top marks should be avoided. If installed, a disposable solution is possible, but environment protection should be considered.

Some polyethylene plastic buoys are suitable for use in ice conditions, see sections 4.4.3.3 and 4.5.2.3.

Additional information is available in the Report of the IALA workshop on challenges of providing AtoN services in polar regions and the IALA Guideline G1108 on The challenges of providing AtoN services in polar regions.

3.12. DESIGN REQUIREMENTS FOR USE OF PLASTIC BUOYS IN VERY HOT CLIMATES

Careful design considerations should be made when using plastic buoys in very hot climates (equatorial regions) as some effects could severely impair the performance of the equipment in place.

The following are examples of problems that may result from prolonged exposure of plastic material to high temperature. They should be considered to help determine if the design is suitable for the application (this list is not intended to be exhaustive).

- parts that bind or corrode from differential expansion of dissimilar materials;
- materials change in dimension, either totally or selectively;
- packing, gaskets, seals, etc. become distorted, bind, and fail causing mechanical or integrity failures;
- gaskets display permanent set;
- closure and sealing strips deteriorate;
- shortened operating lifetime;
- colour fading, cracking or crazing of plastic materials;

- outgassing of plasticizers.

The high rates of solar radiation (UV) in these regions can cause surface temperatures to increase by 15 to 30°C above ambient temperatures and surface temperatures can reach 80°C. As a result, it is important to consider studies made by various manufacturers comparing material degradation, reaction and resilience under these extreme conditions. For additional information, please see the IALA Guideline G1136 on Providing AtoN Services in Extremely Hot and Humid Climates.

3.13. DESIGN REQUIREMENTS FOR USE OF PLASTIC BUOYS IN EXTREME SEA CONDITIONS

Plastic buoys can be used in most sea conditions. However, extreme sea conditions (breaking waves, hurricane, debris) will cause high mechanical stress on buoys. The potential for extreme environmental conditions should be considered when selecting plastic buoys to ensure the design and materials are sufficiently robust to survive.

3.14. HANDLING AND STORAGE

The handling of a plastic buoy generally does not differ from steel buoy handling. The weight of a plastic buoys is typically less than steel buoys making them easier to manoeuvre. The equipment required to lift plastic buoys into place can be a reduced and does not require the same lifting capacity as steel buoys.

Long-term storage should be done according to the manufacturer instructions (for example to avoid deforming of spar buoys).

When plastic buoys are stored outside for a long time (for example on a buoy yard) they should be protected against UV to protect them from premature aging and fading.

3.15. REPAIR & MAINTENANCE

Maintenance procedures are outlined in IALA Guideline G1077 on Maintenance of Aids to Navigation, Annex A2 synthetic buoys.

3.16. QUALITY CONTROL AND TESTING

3.16.1. General

A well-designed and manufactured plastic buoy of good and lasting quality can provide reliable performance at sea for many years with good colour retention and safety of handling.

During the manufacturing process of the buoy body and the metal parts, some important quality control mechanisms should be applied:

- The manufacturer should have an internal quality control procedure, for example ISO 9001 or comparable;
- If required, each buoy can be delivered with a quality control report. The contents of the report should be determined beforehand and satisfy the customer's requirements;
- The customer should establish an internal system to monitor the life cycle of the buoy.

3.16.2. Quality Assurance Tests

In order to ensure the buoy longevity, the following quality tests can be applied.

3.16.2.1. Design Confirmation

Prior to production of prototypes, the design should be thoroughly reviewed to confirm performance expectations. The following reviews are recommended:

- Hydrostatic and hydrodynamic analysis to determine anticipated performance;
- Approval of design for transmission of loads .

3.16.2.2. Prototype Testing before series production

After manufacturing the first samples of plastic parts these could be checked according to the following requirements:

- Measurement of the overall dimensions of each part;
- Measurement of the weight of each part;
- Measurement of the wall thickness on different points;
- Check the water tightness of the enclosed modules by pressure tests;
- Check the surface for imperfections;
- Chromaticity measurements;
- Mechanical tests;
- Sawing of the compartments to get detail information (destructive testing).

In addition to the inspection points described above, the following tests should be performed on the assembled prototype buoys:

- Tension tests up to the anticipated breaking load for all lifting and mooring points;
- Hydrostatic stability tests to confirm actual performance versus anticipated performance (for detail information see IALA Guideline G1099 on the Hydrostatic design of buoys.

3.16.2.3. Manufacturing Quality Control tests

Depending on customer requirements the following tests can be performed on each buoy body or batch:

- Measurement of the overall dimensions;
- Measurement of the weight;
- Measurement of the wall thickness at different points;
- Checking the water tightness;
- Checking the integrity of the foam filling (if applicable);
- Tension tests up to a specified work load;
- Check the surface finish;
- Chromaticity measurements (in accordance with IALA Recommendation R0108 (E-108) on Surface Colours Used as Visual Signals on Marine Aids to Navigation.

3.16.2.4. Testing during the service life

The IALA Guideline G1077 on Maintenance of Aids to Navigation, Annex A2 synthetic buoys gives general information regarding the maintenance of plastic buoys.

In particular, the following tests should be performed at regular intervals:

- Chromaticity measurement to ensure continued compliance with the requirements of IALA Recommendation R0108 (E-108) – Surface Colours Used as Visual Signals on Marine Aids to Navigation;

- Inspection of the buoy for deterioration, tension tests to verify assumptions regarding the anticipated useful life and safety of all lifting components.

3.17. RECYCLING / DISPOSAL

Buoy designs and materials should be selected to minimise their environmental impact upon disposal at the end of their useful life. Considerations should be given to the three "R's" of environmental protection, namely reuse, waste reduction and material recycling. Also, it is desirable that manufacturing processes be environmentally friendly. The buoy design proposed is 100% recyclable. The following table gives information about the recycling possibilities of different materials used for plastic buoys.

Additional Information is available in IALA Guideline G1036 on Environmental Management in Aids to Navigation.

Table 1: Recycling possibilities of different materials used for plastic buoys

Component	Material Type	Ease of Recycling	Recycling Method
Hull	Polyethylene	Easy – Readily Accepted	Plastics Recycling Depot
	Polyurethane Foam	Is to separate from the other buoy materials	Plastics Recycling Depot
	Glass reinforced plastic (GRP)	Not recyclable	
Foam Filling	Fused Expanded Polystyrene	Easy – Readily Accepted	Plastics Recycling Depot
	Polyurethane Foam	Is to separate from the other buoy materials	Plastics Recycling Depot
Superstructure	Polyethylene	Easy – Readily Accepted	Plastics Recycling Depot
	Aluminium	Easy – Readily Accepted	Metal Recycling Depot
Radar Reflector	Aluminium	Easy – Readily Accepted	Metal Recycling Depot
Ladders & Railings	Stainless Steel	Easy – Readily Accepted	Metal Recycling Depot
	Aluminium	Easy – Readily Accepted	Metal Recycling Depot
Core Structure	Polyethylene	Easy – Readily Accepted	Plastics Recycling Depot
	Galvanized Steel	Easy – Readily Accepted	Metal Recycling Depot
Lifting & Mooring Connection Bars	Stainless Steel	Easy – Readily Accepted	Metal Recycling Depot
	Galvanized Steel	Easy – Readily Accepted	Metal Recycling Depot
Threaded Inserts	Stainless Steel	Easy – Readily Accepted	Metal Recycling Depot
	Brass	Easy – Readily Accepted	Metal Recycling Depot
Fasteners	Stainless Steel	Easy – Readily Accepted	Metal Recycling Depot
	Galvanized Steel	Easy – Readily Accepted	Metal Recycling Depot
	Aluminium	Easy – Readily Accepted	Metal Recycling Depot
Ballast	Concrete	Easy – Readily Accepted	Clean Fill Designated Infill
	Steel	Easy – Readily Accepted	Metal Recycling Depot
	Cast Iron	Easy – Readily Accepted	Metal Recycling Depot

4. POLYETHYLENE PLASTIC BUOYS

4.1. POLYETHYLENE MATERIAL – GENERAL

Polyethylene is a thermoplastic. At a temperature of about 100°C it behaves plastically and after cooling the material solidifies. Thus, it can be easily formed and welded under the influence of heat. This provides the ability to make repairs to plastic buoys made of polyethylene. The high ductility and the high cold break resistance are advantageous.

Within the polyethylene family, there are different types of plastic that have different densities and molecular structures and therefore different material properties. The most common types used in the manufacturing of plastic buoys are:

- Linear Low Density Polyethylene (LLDPE);
- Low Density Polyethylene (LDPE);
- Medium Density Polyethylene (MDPE);
- High Density Polyethylene (HDPE);
- Ultra High Density Polyethylene (UHDPE);

The following table gives an overview about the polyethylene types and the manufacturing processes for each.

Table 2: Polyethylene types and the manufacturing processes

Polyethylene Resin Type	Rotational Moulding process	Extrusion process
Linear Low Density, Low Density, Medium Density	X	
High Density		X

The key difference between the two methods of forming the plastic is the use of pressure.

- The rotational moulding process uses only heat to transform plastic resin into a finished shape.
- Plastic pipes and plates manufactured in an extrusion process are formed using heat under high pressure which forms strong molecular chains resulting in greater strength, impact and abrasion resistance.

The different polyethylene types and their different manufacturing processes lead to two main polyethylene plastic buoy types:

- “rotational moulded polyethylene plastic buoys” made of plastic parts fabricated by the rotational moulding process, see section 4.4;
- “high density polyethylene plastic buoys” made of plastic parts fabricated with high-density polyethylene pipes, plates and components, see section 4.5.

4.2. MECHANICAL PROPERTIES AND STANDARDS FOR POLYETHYLENE

The following mechanical properties of polyethylene material must be carefully chosen as base for a high quality plastic buoy. They can be tested according to the standards named in brackets behind them.

- density (ISO 1183/ASTM D-4883/ASTM D-1505);
- hardness (DIN 53505);
- yield strength (DIN EN ISO 527-1, DIN EN ISO 527-2);
- fracture strength (DIN EN ISO 527-1, DIN EN ISO 527-2);
- elongation (DIN EN ISO 527-1, DIN EN ISO 527-2);
- abrasion resistance (DIN 53516);
- impact resistance (ISO 6603-2).

4.3. GENERAL CONSIDERATIONS WITH REGARD TO THE CONSTRUCTION OF POLYETHYLENE PLASTIC BUOYS

4.3.1. WALL THICKNESS

The wall thickness of the plastic parts should be optimised for the buoy size, its shape and the intended use. The range is from 5 – 40 mm.

4.3.2. RESERVE BUOYANCY

The composition of a buoy of several enclosed modules offers the advantage that a reserve of buoyancy remains in case of damage to one or modules.

A safety buoyancy also can be achieved by filling the buoy body with floatation material according to chapter 4.3.5.

4.3.3. MULTI COLOUR POSSIBILITIES

The composition of a buoy with different parts or several enclosed modules offers the advantage that multi-colour buoys can be realised. Examples of these buoys can be found in the chapters in which the different buoy types are described.

4.3.4. EXPANSION AND SHRINKAGE OF POLYETHYLENE PLASTIC PARTS

Polyethylene material will expand and contract about 3 to 5 %, depending on the colour and ambient temperature. Care should be taken in the design to ensure compatibility between different materials (e.g. elongated or oversized clearance holes).

4.3.5. FILLING POLYETHYLENE PLASTIC BUOYS

Polyethylene plastic buoys can be filled with polystyrene or polyurethane foam, which can have the following advantages:

- Filling could increase the impact stability/shock resistance;
- In case of leakage the filling can prevent the buoy from sinking.

If filling is used, it must be of the highest quality closed-cell specification to prevent water absorption.

Information about the density and the water absorption behaviour of the foam should be taken in to consideration.

Filling material should be of sufficient quality to survive the expected lifetime of the buoy.

Some disadvantages may exist in the use of foam filling:

- Some polyurethane foam types may not be recyclable. Furthermore the combination of polyethylene and foam is not easy to separate.
- For filling foam into the floats additional holes are necessary. These are weak spots and must be closed carefully after the filling.

Figure 8: Polystyrene foam

Figure 8 shows a rotational moulded float filled with polystyrene foam, Figure 9 shows a polyurethane foam filled float. High density polyethylene buoys are frequently filled with polystyrene billets as shown in Figure 10.

Figure 9: Polyurethane foam

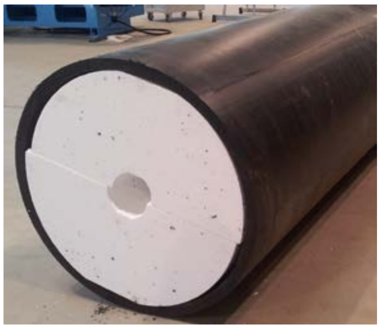

Figure 10: Polystyrene billets

4.3.6. ADHESION OF COLOUR OR FOILS FOR BUOY LETTERING

Polyethylene provides poor adhesion for conventional paints or foils for buoy lettering. Specialized hot plastic spraying processes or “Mould in Graphics” are available and have been used successfully. For further information see section 3.10.

4.4. ROTATIONAL MOULDED POLYETHYLENE PLASTIC BUOYS

A great variety of different types and sizes of rotational moulded polyethylene plastic buoys is available on the market. Depending on the type, size/diameter and area of application different designs of polyethylene plastic buoys exist. Generally, small buoys are made from one or more enclosed modules, while larger types may be modular plastic or hybrid metal/plastic.

The following sections give an overview of the manufacturing procedure of rotational moulded plastic parts and typical rotational moulded plastic buoys.

4.4.1. MANUFACTURING OF ROTATIONAL MOULDED POLYETHYLENE PLASTIC PARTS

Rotational moulding can be used for the production of large, hollow, seamless plastic parts (enclosed modules). During the rotational moulding process the base resin (Low Density, Linear Low Density, Medium Density) is transformed with heat only.

A thin-walled hollow mould gives the outer shape of the plastic part. The mould is filled with plastic powder, is then slowly rotated multi-axially, and heated. The melting temperature of the plastic depends on the plastic material used (Figure 11 and Figure 12).

Figure 11: Mould filled with plastic powder

Figure 12: Closed mould

During the heating process, the plastic resin becomes molten and slowly settles on the inner mould surface, the multi-axial rotation is programmed to create a relatively uniform distribution of the plastic. The plastic is heated until it is properly cured and then the cooling phase of the process begins. The wall thickness depends on the amount of plastic resin used and this will determine the amount of time required to properly cure the plastic. Wall thicknesses may be from 5 mm to 40 mm depending on the required strength and design of the buoy (Figure 13).

Figure 13: Opened mould

It is also possible to integrate metal parts into the plastic parts during the moulding process used for mooring and lifting and fastening systems (Figure 14).

Figure 14: Insert

Rotational moulding is particularly suitable for small to medium series production. The advantages are the relatively low mould costs and the almost unlimited possibilities of shaping.

The enclosed modules, manufactured as described above, can either be used directly as a buoy, be welded to buoys or mounted as floats on a core structure.

Figure 16 shows a small enclosed module (small marker, 0.5 m diameter, 0.7 m height), Figure 15 shows a big enclosed module (float, length 2.17 m, outer radius 1.21 m, wall thickness 20 mm).

Figure 16: Small marker

Figure 15: Float

4.4.2. MANUFACTURING OF ROTATIONAL MOULDED POLYETHYLENE BUOYS MADE BY ONE ENCLOSED MODULE

Rotational moulded plastic buoys made of one enclosed module are often used as small harbour or river markers.

The lifting and the mooring eyes are made as a part of the plastic body (Figure 17) or from additional metal components (Figure 18).

The application of these (small) plastic buoys usually requires only a monochrome version, the multi-colour variant is not needed.

Typical technical data are:

Table 3: Small harbour or river markers

Parameter	Value
application area	harbour, rivers, marinas
diameter in the water line (m)	≈ 0.5
height above water line/focal plane (m)	≈ 2
height over all (m)	≈ 3

Figure 17: Plastic lifting eye

Figure 18: Metal lifting and mooring eyes

4.4.3. MANUFACTURING OF ROTATIONAL MOULDED POLYETHYLENE PLASTIC BUOYS MADE BY TWO OR MORE ENCLOSED MODULES, WELDED

4.4.3.1. Manufacturing procedure of rotational moulded polyethylene plastic buoys, welded

Buoys, which consist of two or more enclosed modules, are usually welded together from rotational moulded plastic parts. Figure 19 and Figure 20 are showing the welding process (butt fusion welding).

Figure 19: Butt fusion welding

Figure 20: Butt fusion welding

The advantages of this modular design using enclosed modules can be:

- The wall thickness of the lower elements can be made bigger than from the upper elements because of stability and ballast reasons;
- The underwater elements do not necessarily have to be executed in the traffic-efficient colour (cost savings);
- Multi-colour buoys can be realised easily;
- The buoy can be divided into a few waterproof sections (reserve buoyancy);
- The radar reflector and other devices can easily be placed inside the buoy body (upper part).

4.4.3.2. Typical spar- and conical buoys, rotational moulded, welded

Widely used spar- and conical buoys up to 1.5 m are the buoys described in the following table (3 typical sizes).

Table 4: Typical spar and conical buoys, welded

Parameter	big spar/conical buoy	middle spar/conical buoy	small spar/conical buoy
application area	sea, coast, estuary	coast, estuary	estuary, shallow water
biggest diameter in the water line (m)	≈ 1.0 – 1.6	≈ 0.8 – 1.0	≈ 0.4 - 0.8
height above water line/focal plane (m)	≈ 3	≈ 2.6	≈ 2
height over all (m)	≈ 6	≈ 5 - 6	≈ 2 - 5

Figure 22 and Figure 23 are showing examples. Figure 21 shows an exploded drawing and the possibility to realise multi-coloured plastic combinations. By welding individual plastic parts or enclosed modules, the required color combinations can be realised.

Figure 22: Conical buoy

Figure 23: Spar buoy

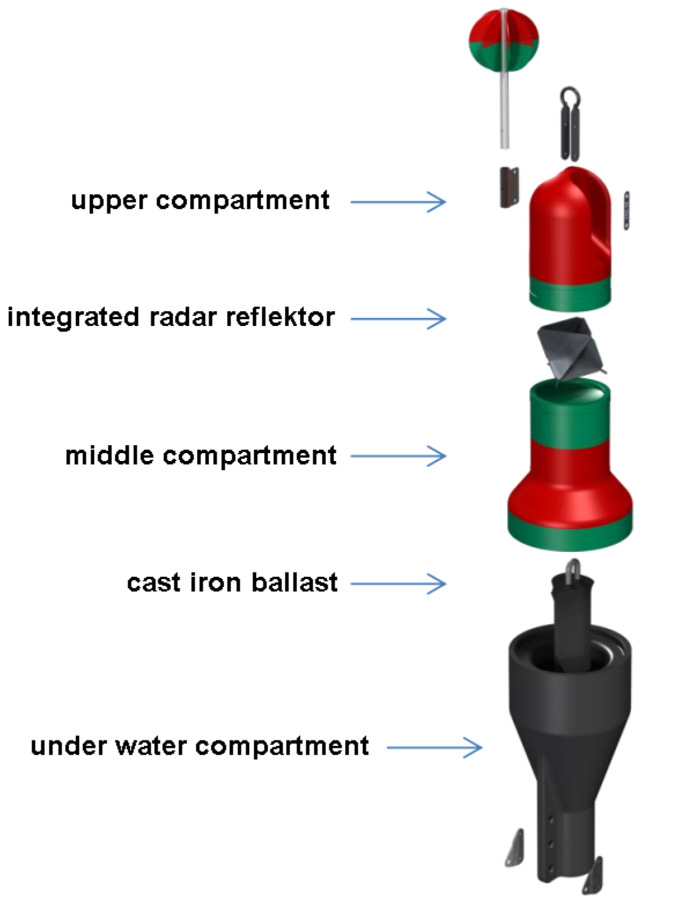

Figure 21: Exploded drawing

4.4.3.3. Use of rotational moulded welded spar and conical buoys in ice built up areas

For general demands concerning the design and use of plastic buoys in ice conditions, see section 3.11. Rotational moulded welded plastic buoys may be used in operational areas with light ice conditions. An example of a rotational moulded conical buoy in light ice is shown in Figure 24.

It is the movement of ice and especially free flowing ice that causes damage to the buoys. The type of rotational moulding polyethylene and the wall thickness of the hull are critical for survival. Manufacturers should state the ice resistance capability for rotational moulded plastic buoys. In aggressive ice conditions the use of high density polyethylene plastic buoys (see section 4.5) with greater strength and abrasion resistance are recommended.

Figure 24: Conical buoy in light ice

4.4.3.4. Typical spars, rotational moulded, welded

Spars with the following characteristics are common, two typical types are shown:

Table 5: Typical spars, rotational moulded, welded

Parameter	Small spar	Medium spar
application area	marinas, inland waterways	coastal, ports, inland waterways
diameter (m)	≈ 0.25 – 0.4	≈ 0.4 – 0.6
height above water line/focal plane (m)	≈ 0.75 – 1.5	≈ 1.5 – 2
height over all (m)	≈ 2 – 3	≈ 4 – 5

Figure 25 and Figure 26 show examples.

Figure 25: Spar

Figure 26: Spar

4.4.4. MANUFACTURING OF MODULAR PLASTIC BUOYS WITH ROTATIONAL MOULDED ENCLOSED MODULES AS FLOATS

For bigger plastic buoys (diameter more than 1.5 m up to 4 m) rotational moulded enclosed modules are used as floats.

The floats are mounted on a core structure, which consists of plastic pipes (complete plastic design, section 4.4.4.1) or a metal construction (hybrid metal/plastic design, section 4.4.4.2).

The advantage of the modular design are:

- The modular design can simplify handling and transport;
- Defective parts can be changed easily;

These plastic buoys can withstand light ice conditions. The effect of ice growth has to be considered (Figure 27).

Figure 27: Ice growth

4.4.4.1. Modular plastic buoys with complete plastic design

Modular buoys with a plastic core structure (complete plastic design) consist at least of the following elements (Figure 28):

- enclosed modules as floats;
- polyethylene tail tube (HDPE);
- polyethylene superstructure;
- mooring and lifting eyes made of steel;
- cast iron ballast weight.

The main advantage of these buoys is that no maintenance is required (except the mooring and lifting eyes).

Multi-colour-combinations can be realised as follows:

- The floats can be made of different colours;
- They can be combined according to the needed colour combination;
- On a polyethylene superstructure a cap with the needed colour combination can be mounted;

Figure 28: Exploded drawing

- It is also possible, to mount coloured polyethylene plates on the polyethylene superstructure (Figure 29).

Figure 29: Coloured polyethylene plates on polyethylene superstructure

4.4.4.2. Modular plastic buoys with hybrid metal/plastic design

Modular buoys with hybrid metal/plastic design are consisting at least of the following elements (Figure 30):

- enclosed modules as floats;
- steel tail tube or skirt;
- aluminium or plastic superstructure;
- mooring and lifting eye made of steel;
- cast iron ballast weight.

Multi-colour-combinations can be realised as follows:

- The floats can be made of different colours and combined according to the needed colour combination
- An aluminium superstructure can be painted with different colours (Figure 31);
- Other possibilities are the mounting of a cap with the needed colour combination or coloured polyethylene plates.

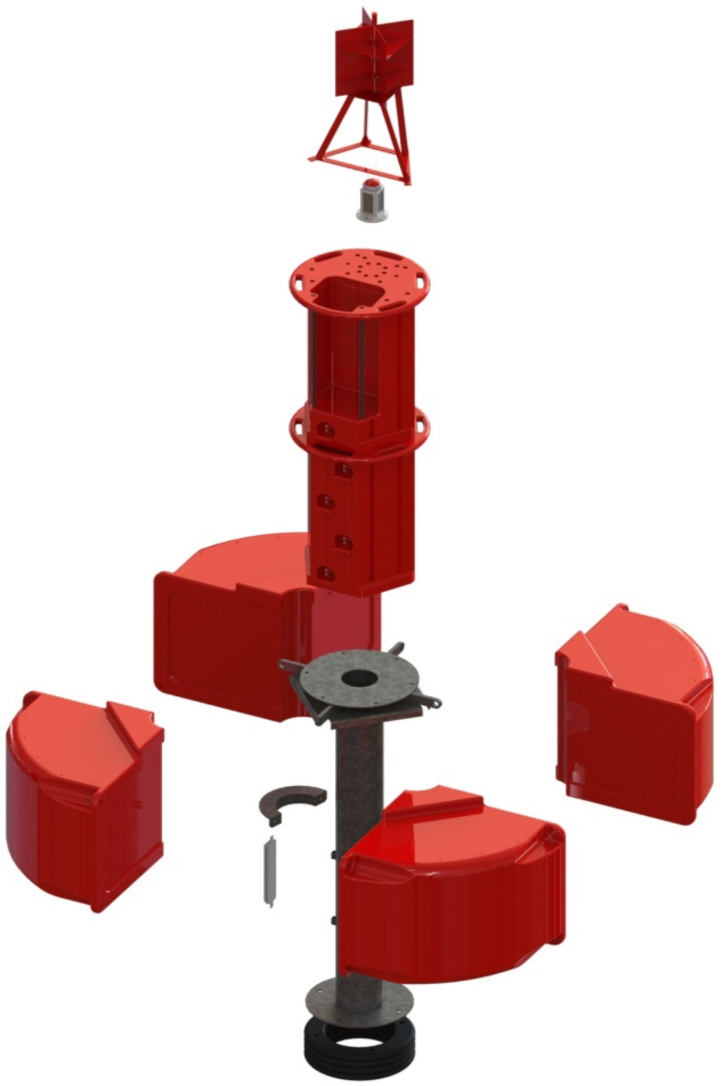

Figure 30: Exploded drawing

Figure 31: Painted aluminium superstructure

4.4.4.3. Typical modular plastic buoys with enclosed modules as floats

The following sizes of modular plastic buoys with polyethylene floats are typical, regardless of whether it is the complete plastic design (section 4.4.4.1) or the hybrid metal/plastic design (section 4.4.4.2):

Table 6: Typical modular buoys

Parameter	small modular spar/conical buoy	middle modular spar/conical buoy	big modular spar/conical buoy
application area	coastal, shelter, rivers, ports	open sea, coastal, estuary	open sea estuary
biggest diameter in the water line (m)	≈ 1.5/1.8/2	≈ 2.2 -2.6	≈ 3 - 4
height above water line/focal plane (m)	≈ 1.7 - 4.2	≈ 3.8 - 6.5	≈ 5 - 8
height over all (m)	≈ 2.7 - 7.9	≈ 8.6	≈ 12 - 15

Figure 32 and Figure 33 show plastic buoys in complete plastic design.

Figure 32: Complete plastic design, 3 modules

Figure 33: Complete plastic design, 2 modules

The buoy shown in Figure 35 is an example for a hybrid metal/plastic design.

It is equipped with grey polyethylene floats and a high visibility metallic spar, offering the day mark of the buoy. See IALA Guideline G1094 on Daymarks for Aids to Navigation.

4.5. HIGH DENSITY POLYETHYLENE PLASTIC BUOYS

4.5.1. MANUFACTURING OF HIGH DENSITY POLYETHYLENE PLASTIC PARTS

4.5.1.1. Pipes manufactured by extrusion-process

Plastic extrusion is a high-volume manufacturing process in which plastic is melted and formed into a continuous profile. The base resin is transformed with heat under significant pressure. This process is used to produce tubes/pipes, plates etc.

Figure 34: Extrusion process

The significantly higher molecular weight of the high density resin and the extrusion process create a material with significantly greater strength, abrasion and impact resistance than the polyethylene formed in rotational moulding.

Figure 35: Hybrid metal/plastic design

Figure 36: Co-extrusion

The process starts with feeding plastic from a funnel into the extruder. In the extruder, the plastic is compacted by a rotating screw, melted and pressed through a nozzle. The nozzle gives the end product its profile. This is followed by the cooling process, which is usually achieved by a water bath. Figure 34 shows pipe manufacturing by extrusion process.

Figure 37: Extruded pipes

Pipes can be extruded in a single colour or they may be extruded with the outside 20% in a separate colour, this process is called “co-extrusion”, the main part of the wall thickness is in black. (Figure 36).

Pipes used for polyethylene buoys are mainly used in pressured lines like water and other liquids. The most common material is HD 100 polyethylene. The wall thickness and the pressure class vary depending on the SDR (Standard Dimension Ratio). Typical for buoy applications are SDR 17 and SDR 26. Figure 37 shows extruded pipes as raw material for spars.

4.5.1.2. Other high density polyethylene plastic parts

Other polyethylene plastic parts (mainly the smaller and special parts) can be made by the cutting of high density polyethylene plates, pipes and compression moulded parts, etc., see Figure 38. A combination with metal parts is also possible (Figure 39).

Figure 38: Compression moulded parts

Figure 39: Combination plastic and metal parts

4.5.2. MANUFACTURING OF HIGH DENSITY POLYETHYLENE PLASTIC BUOYS

High Density Polyethylene plastic buoys are fabricated by skilled technicians using extruded HDPE pipes, HDPE plates and small HDPE parts. The manufacturing process includes the cutting and welding of the components to create the desired design shape.

A number of different design shapes can be achieved but there are some limitations based on the diameters of extruded pipes used as floats. As a result, the majority of buoys have a spar type shape.

Larger buoys are fabricated with bulkheads to form several watertight buoyancy modules that offer the advantage of reserve of buoyancy in case of damage to one or more segments. Additional security of the reserve buoyancy is also achieved by filling the buoy body with floatation material like polystyrene, see chapter 4.3.5.

Buoy manufacturing by welding together extruded pipe sections is particularly suitable for small series production and customised buoy solutions. The advantages are a robust body of extruded pipe with the possibility to integrate components and devices inside the buoy body. It is possible to attach metal parts with bolts parts or plastic inserts by extrusion welding. In either case the skin of the buoy distributes loads evenly to the whole buoy body.

Standards for the extrusion-made pipes are:

- EN 12201-1, plastics piping systems for water supply Polyethylene (PE). Part 2: Pipes;
- EN ISO 1133, plastics – Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics (ISO 1133:1997);
- EN ISO 2505, thermoplastics pipes. longitudinal reversion. Test method and parameters (ISO 2505:2005);
- EN ISO 3126, plastics piping systems – Plastics piping components – Measurement and determination of dimensions;
- EN ISO 6259-1, thermoplastics pipes. Determination of tensile properties. Part 1: General test method (ISO 6259-1:1997);
- EN ISO 13920, Welding- General tolerances for welded constructions – Dimensions for length and angles Shape and position;
- ISO 6259-3, Thermoplastics pipes – Determination of tensile properties – Part 3: Polyolefin pipes;
- ISO 13953, Polyethylene (PE) pipes and fittings – Determination of the tensile strength and failure mode of test pieces from a butt-fused joint;

- ISO 16770, Plastics – Determination of environmental stress cracking (ESC) of polyethylene – Full-notch creep test (FNCT);
- ISO/TR 10358, Plastics pipes and fittings – Combined chemical-resistance-classification table.

HDPE pipes can be joined together by butt fusion welding, the resulting fusion weld is stronger than the pipe (Figure 40). This process allows pipes of different colours to be joined together and permits the creation of watertight sections with the addition of internal bulkheads.

HDPE plates and parts can be joined to the pipes using an HDPE Extrusion Welding process which utilises heat to bond molten HDPE welding wire to the surfaces between pipe and plate (Figure 41). This process is typically used to add strengthening plates for lifting and to make transitions between components strong and watertight.

The possibilities to produce multi-colour plastic buoys according to the IALA maritime buoyage system (MBS) are as follows:

- Enclosed modules can be made of different colours. They can be welded together according to the needed colour combination;
- Extruded pipes can be manufactured in multi colour combinations (for example red-white). The different multi coloured plastic pipes can be welded together (Figure 42);
- Other possibilities are the welding of coloured plastic plates on the buoy body or the mounting of a cap with the needed colour combination.

There is a large range of high density polyethylene plastic buoys types and sizes available on the market. The following chapters give an overview about the most common types.

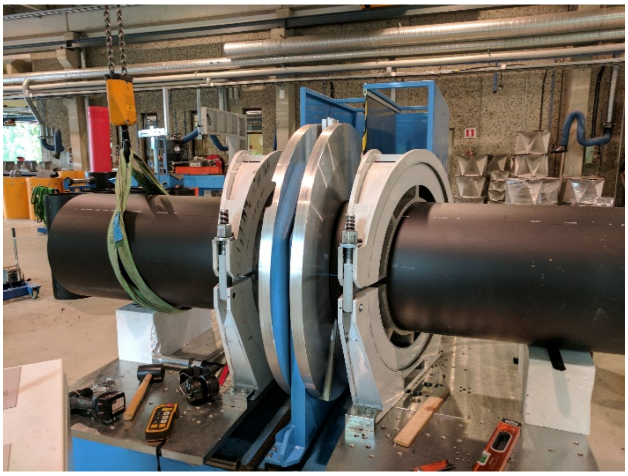

Figure 40: Butt fusion welding

Figure 41: HDPE extrusion welding

Figure 42: Multi coloured plastic pipes

4.5.2.1. Typical high density polyethylene spar and conical plastic buoys

Widely used as spar- and conical buoys up to 1.5m are the buoys described in the following table (3 typical sizes). Figure 43, Figure 44 and Figure 45 are showing examples.

Table 7: Typical high density polyethylene spar- and conical-buoys

Parameter	Large spar/conical buoy	Middle spar/conical buoy	Small spar/conical buoy
application area	sea, coast, estuary	coast, estuary	estuary, shallow water
biggest diameter in the water line (m)	≈ 1.0 – 1.6	≈ 0.8 – 1	≈ 0.4 - 0.8
height above water line/focal plane (m)	≈ 3	≈ 2.6	≈ 2
height over all (m)	≈ 6	≈ 5 - 6	≈ 2 - 5

Figure 43: Spar buoy afloat

Figure 44: Multi colour spar buoy

Figure 45: Spar buoy

4.5.2.2. Typical high density polyethylene plastic spars

Most HDPE spars consist mainly of one or more plastic pipe sections manufactured by an extruding-process. The top and the bottom parts are also made of plastic and become mainly fusion welded on the pipe(s).

- The buoy can be divided into a few waterproof sections;
- Radar reflector and other devices are usually placed inside the buoy body;
- Buoys can be easily customized according to specifications;
- They can be equipped with a light-unit (self contained (IPSL) or battery powered);
- The buoys are usually filled with polystyrene or polyurethane foam;
- Most spars can be used can be used as "all-year-round" buoys in ice covered areas;
- The large spars with thick walls of greater than 30 mm can be used as ice buoys in arctic areas.

Spars with the following characteristics are common. Figure 46, Figure 47 and Figure 48 show examples.

Parameter	Small spar	Medium spar	Large spar
application area	marinas, inland waters	coastal, ports, inland waters	offshore, coastal
diameter (m)	≈ 0.16 – 0.3	≈ 0.4 – 0.7	≈ 0.8 – 1
height above water line/focal plane (m)	≈ 2.0 – 3	≈ 2.5 – 3.5	≈ 3.0- 4
height over all (m)	≈ 2.5 – 6	≈ 6.0 – 9	≈ 8.0 – 11

Table 8: Typical high density polyethylene plastic spars

Figure 46: Multi-colour spar

Figure 47: Spar afloat

Figure 48: Spar with top mark

4.5.2.3. Use of high density polyethylene plastic buoys in ice build-up areas

For general demands concerning ice stable design of plastic buoys see section 3.11.

Plastic buoys made of extruded HDPE plastic, which is characterised by increased strength and abrasion resistance, are particularly recommended for use under aggressive conditions.

Figure 49 and Figure 50 show a high density polyethylene plastic buoy frozen in a solid ice-field. Figure 51 demonstrates buoy use in crushed ice.

The main reason for destruction of plastic buoys by ice is insufficient strength in the buoy hull. The wall thickness and the polyethylene material should be chosen to suit the application and manufactured homogeneously during the production process.

Figure 49: Spar in solid ice field

Figure 50: Spar buoy in solid ice field

Figure 51: Spar in crushed ice

5. GLASS REINFORCED PLASTIC (GRP)

5.1. GENERAL

GRP is the usual abbreviation for glass reinforced plastic which in its most common form consists of glass matt bonded by polyester resin.

5.2. CONSTRUCTION

Complex shapes can be produced by laying-up resin and glass reinforcement into a mould by hand (or spray machine). The cylindrical buoy body is normally formed by joining two half body shapes. It is important to note that the joint is often the weakest area of the body.

The strength of GRP is dependent of the ratio of glass fibre to resin and thus this is another area which requires definition and quality control. High strength (required in ice conditions) can be achieved by the use of carbon or Kevlar fibres but the costs may be high. These fibres may be used in specific stress areas of the buoy.

The outer layer of resin, the gel coat, prevents water absorption into the glass reinforcement and should be protected from mechanical damage. This is usually provided by some form of fendering.

5.3. EXAMPLES OF GRP BUOYS

Figure 52 and Figure 53 show samples of GRP buoys.

Figure 52: GRP buoy

Figure 53: GRP buoy afloat

5.3.1. FILLING

In the event of a collision, a GRP buoy may well crack from an impact which would only dent a steel buoy. To prevent the buoy from sinking it should be divided into separate watertight compartments or filled with polyurethane foam or polystyrene foam.

5.3.2. FASTENERS / MOORING ATTACHMENT

Care should be taken when bonding metal attachment points into GRP due to the considerable difference in thermal expansion rates between metals and plastics, and the inherent flexibility of the GRP. Another option is to use through bolted fixings with generous backing plates and resilient washers or coatings between the metal and the GRP.

5.4. REPAIR AND MAINTENANCE

GRP buoys will require cleaning, repainting and any necessary repair to the gel coat.

Repair of GRP is usually straightforward but does require standards of cleanliness and specific working temperatures. Effective drying of damaged laminates or foam cores may also be difficult in cold climates. It may be necessary to use heaters to warm and dry damage areas and to ensure effective curing of the repair.

The final surface colour of GRP buoys can be incorporated into the gel coat. If this not the case or if a colour change is required, then buoys will require normal painting to achieve the required surface colours.

GRP buoys may be cleaned onsite using water jetting. However care should be taken to avoid polluting the surrounding environment with paint flakes and surface materials.

The area in which foam filled buoys are used should be considered since oily water in around the port environment could penetrate damaged buoys, making the repair of it very difficult.

6. POLYURETHANE / ELASTOMER COATED FOAM

6.1. ELASTOMER MATERIAL – GENERAL

These buoys typically consist of a thick, flexible marine grade polyurethane elastomer skin on a flexible closed cell foam core. They have the advantage of overall flexibility and resilience. The flexibility will also be an advantage when the buoy has to be serviced in rough weather.

The main feature of elastomer buoys lies in its lightweight float of high elasticity, manufactured with closed-cell polyethylene solid foam sheet (no water absorption) and spray coated with a 8 - 20 mm thick layer of coloured polyurethane elastomer.

Thanks to its solid construction, they are virtually unsinkable, even in case of a strong impact. Besides, they can withstand repeated collisions without deforming (recovery capacity). The elastomer polyurethane allows the application of an anti-fouling treatment.

6.2. MECHANICAL PROPERTIES AND STANDARDS FOR ELASTOMER PLASTIC

6.2.1. POLYURETHANE ELASTOMER PROPERTIES

The following mechanical properties of polyurethane elastomer material must be carefully chosen as the base for a high quality plastic buoy. They can be tested according to the standards named in brackets behind them.

- density (BS 4370);
- tensile strength (ISO 527);
- ultimate elongation (ISO 527);
- hardness (DIN 53505);
- breaking resistance (DIN EN ISO 6383-1);
- water vapour diffusion resistance (EN 1931) ;
- fatigue motion resistance (EOTA TR008).

6.2.2. POLYETHYLENE SOLID FOAM SHEET PROPERTIES

Table 9: Polyethylene foam properties

physical condition	solid
colour	coloured
melting point	105 - 110 °C
flash point	420 - 440 °C (ASTM D1929-16)
ignition temperature	430 - 450 °C (DIN 54836)
density	from 30 to 100 kg/m³
water solubility	insoluble
water absorption	1 - 2%

Table 10: Polyurethane elastomer properties

Properties	Value	Result	Method
density	kg/m³	≈ 900	BS 4370
tensile strength	MPa	≈ 17	ISO 527
elongation at break	%	≈ 342	ISO 527
hardness shore (A)		≈ 90	DIN 53505
breaking strength	N/mm	≈ 35	DIN EN ISO 6383-1
fire resistance	self-extinguishing		
thermal resistance	behaves consistently with temperatures -40 °C to +180 °C		

6.3. CONSTRUCTION DETAILS OF ELASTOMER PLASTIC BUOYS

6.3.1. MANUFACTURING OF PLASTIC PARTS

The manufacturing process of the elastomer buoy float is based on a solid rolled body of closed-cell polyethylene foam sheet and bound by heat (Figure 54, Figure 55). No chemical substance is involved in it.

The thickness of the polyurethane elastomer layer should be optimised to the size, the shape, the environmental conditions and the use of the buoy should be sufficiently robust. The most common thickness range used is from 8 – 20 mm.

The rolled body is covered by a coating of elastomer polyurethane (Figure 56); thus forming an elastic skin on an elastic core. So the body buoy is solid, compact, extremely flexible, has a great recovering capacity and zero water absorption. The initial colour of the body is given by the elastomer coating. The elastomer surface allows later painting.

The core of the elastomer buoys may be manufactured from material of varying density, which allows the adaptation to local needs depending on location, environmental conditions or external influences.

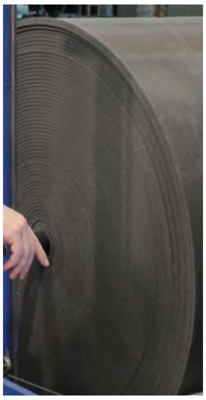

Figure 54: Rolled body of closed-cell polyethylene

Figure 55: Bound closed cell polyethelene post heating

Figure 56: Coating of elastomer polyurethane

On the upper area of the float a coating of silica granulation is applied to provide a non-slip surface for maintenance staff (Figure 57).

The float of elastomer buoys is a solid part, never manufactured in modules. The process of manufacturing and materials used in the elastomer floats are the same as those used in fenders for vessel berthing in ports. They are able to withstand repeated strong collisions. Thus, the replacement of the float is not anticipated.

Figure 57: Non-slip surface

6.3.2. ASSEMBLY OF ELASTOMER BUOY PARTS

The assembly of the buoy involves other parts such as metal structure, tail tube, superstructure, etc. (Figure 58).

It is important to avoid movement or rotation between the plastic and the metallic parts.

Figure 59 shows the assembly of an elastomer buoy (diameter 3m) in horizontal position.

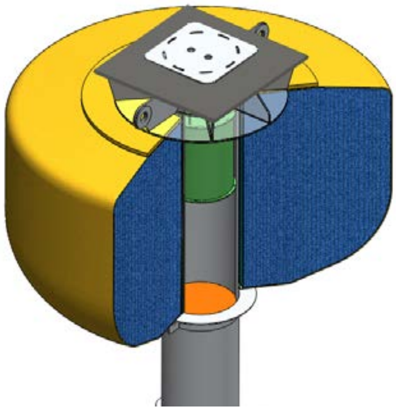

Figure 58: Sectional view of an elastomer buoy

Figure 59: Assemby of an elastomer buoy

6.4. SHAPES AND SIZES OF ELASTOMER BUOYS

As they need no mould, the choice of shapes and sizes is flexible. The diameters of the elastomer buoys on the market are between 0.8 to 3.6 m, the height of the float can be up to 2.8 m. Figure 62 , Figure 61 and Figure 60 show examples of elastomer buoys.

6.4.1. MULTI-COLOUR POSSIBILITIES OF ELASTOMER BUOYS

For producing multi-colour buoys the elastomer provides good adhesion for paints.

6.4.2. USE OF ELASTOMER BUOYS IN ICE BUILT UP AREAS

For general demands concerning the design and use of plastic buoys in ice conditions, see section 3.11.

- The floats of elastomer buoys are flexible and have a good recovering capacity;
- If necessary, an additional reinforcement mesh can be added to the polyethylene foam core or/and the polyurethane elastomer coating.

Figure 62: Solar and wind powered lit elastomer buoy with measurement equipment

Figure 61: Solar powered lit elastomer buoy

Figure 60: Elastomer buoy with self contained lantern

7. IONOMER FOAM BUOYS

7.1. GENERAL

The life and durability of ionomer foam buoys is entirely dependent on the quality of the foam used. The flexibility of the foam can provide good impact resistance but the resistance to aggressive abrasion is not good. This last factor is important for buoys which dry out on a hard bottom at a tidal site or may be subject to moving ice conditions.

A foam buoy hull can sustain considerable damage or loss of material without sinking. A damaged buoy cannot be repaired by the user. The material is not recyclable.

7.2. CONSTRUCTION

These buoys are usually constructed by wrapping closed-cell foam (ionomer foam which is produced in sheet form) around a central structural core. The layers of foam are heat sealed together during the wrapping process. The outer layer of the rolled foam can be "densified" through the application of pressure and heat to make a hard, smooth surface.

Colour pigments are usually incorporated into the foam during the extrusion process, so the colour is continuous throughout the entire hull and daymark. The buoys include a structural steel framework, steel lifting and mooring eyes and stainless steel connecting hardware.

The manufacturing technique particularly lends itself to the production of one-off designs as a variety of body shapes can be made without the need for a mould. Buoys of this type are significantly lighter than steel buoys of the same size.

7.3. EXAMPLE OF IONOMER FOAM BUOY

Figure 63 shows an example of an ionomer foam buoy.

Figure 63: Ionomer foam

8. BUOY EQUIPMENT

Similar to steel buoys, additional equipment can be mounted in or on plastic buoys. The following sections give an overview about such components.

8.1. LIGHT UNITS

Plastic buoys can be equipped with lanterns (powered by solar, wind or wave energy or by a primary battery) or self-contained lanterns (Integrated Power Systems Lanterns (IPSL)).

IPSL are becoming increasingly smaller. At the same time, their functionality increases. The IALA NAVGUIDE 2018 and the IALA Guideline G1064 on Integrated Power Systems Lanterns give information in detail.

If the plastic buoy is used in ice conditions according to sections 3.11, 4.4.3.3 and 4.5.2.3, the self-contained lantern or the stand alone lantern must also be designed to be ice-resistant. On some plastic buoys (especially spars) a primary battery instead of a solar power supply is used.

8.2. MONITORING SYSTEMS AND SENSORS

Modern IPSL can be equipped with remote monitoring and remote control system or sensors. Depending from the buoy location different communication methods for data transfer can be used.

The status of the lantern, the power supply and other devices as well as buoy-related data can be acquired, transferred and displayed. This enables further optimisation of the technical maintenance operation, especially with regard to the cost intensive buoy tender fleet.

The IALA Guideline G1008 on Remote Control and Monitoring of Aids to Navigation gives information in detail.

8.3. RADAR REFLECTOR

A radar reflector is a passive device designed to enhance the radar conspicuity of aids to navigation (Figure 64). The IALA NAVGUIDE provides more information.

Most plastic buoys are equipped with a radar reflector, mounted inside or outside of the buoy body.

The advantage of an integrated radar reflector is that the radar reflector is protected from environment conditions.

The disadvantage is, that the surrounding plastic wall reduces the reflection performance (RCS) of the radar reflector. The effects have to be taken into consideration. According to experience/measurements the reduction of the reflection performance of polyethylene plastic material is only small.

Generally the radar reflector should not be mounted behind conducting components, for example solar panels, lettering plates, etc.

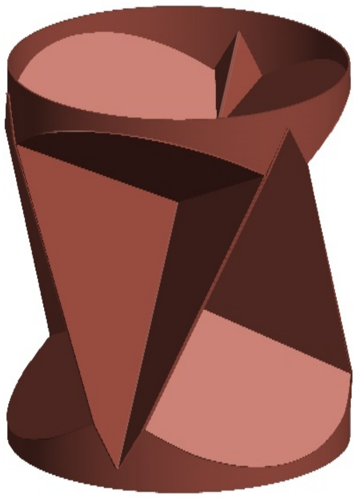

Figure 64: Radar reflector

8.4. RACON

A radar beacon (racon) enhances the radar detection and identification of the object on which it is mounted. For detail information refer to the IALA- NAVGUIDE and the IALA Guideline G1010 on Racon Range Performance.

8.5. AIS

Buoys can be equipped with AIS-transponders to transmit different messages. Remote monitoring is also possible. For detailed information please refer to IALA Recommendation A-126 on the Use of the Automatic Identification System (AIS) in Marine Aids to Navigation Services and IALA Guideline G1098 on The Application of AIS - AtoN on Buoys".

8.6. TOP MARKS

The shape and the dimensions of top marks are described in IALA Guideline G1094 on Daymarks for Aids to Navigation. Top marks can also be designed to enhance the radar response.

The use of top marks should be avoided in ice build-up areas, because they can be damaged by ice.

8.7. RETROREFLECTIVE MATERIAL

Plastic buoys can be equipped with retroreflective material, so the mariner can detect the position and colour at night by use of a searchlight (Figure 65).

For detail information look at the IALA Guideline G1094 on Daymarks for Aids to Navigation and the IALA Recommendation R0106 (E-106) on Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.

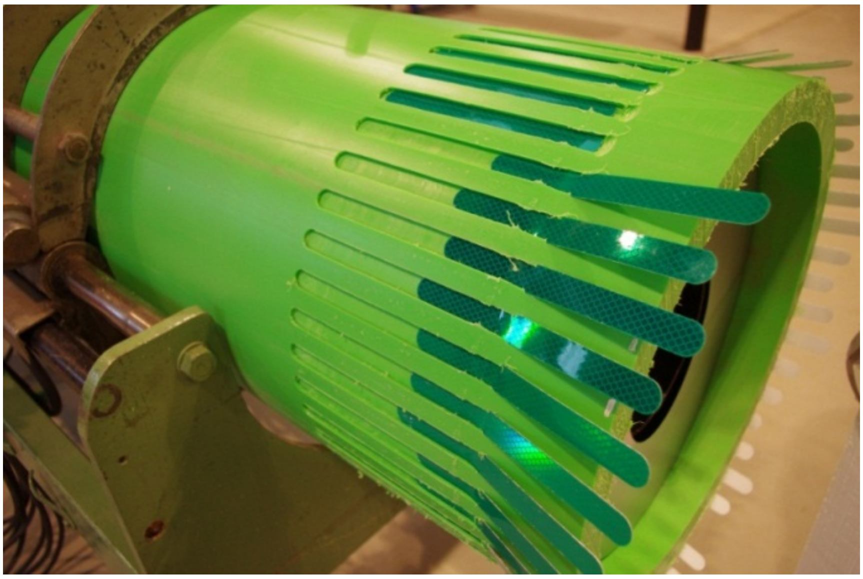

Figure 65: Buoys with retroreflective stripes, mounted in a recess

9. ACRONYMS & DEFINITIONS

9.1. ACRONYMS

AIS	Automatic Identification System
ASTM	American Society for Testing and Materials
AtoN	Aids to Navigation
BS	British Standard
°C	Degrees Celsius
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
DIN	Deutsches Institut für Normung
EN	European Norm
EOTA	European Organisation for Technical Assessment
ESC	Environmental Stress Cracking
FNCT	Full-notch Creep Test
GRP	Glass Reinforced Plastic
HDPE	High density Polyethylene
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM
IPSL	Integrated Power System Lantern
ISO	International Organisation for Standardisation
kg	Kilogram
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MDPE	Medium Density Polyethylene
m	metre
m^3	cubic metre
MBS	Maritime Buoyage System
MFR	Mass-Flow Rate
mm	millimetre
MPa	Mega Pascal
MVR	Melt Volume-flow Rate
N	Newton
NCS	Natural Colour System
nm	nanometre

PE	Polyethylene
RACON	Radar Beacon
RADAR	Radio Detection and Ranging
RCS	Radar Cross Section
SDR	Standard Dimension Ratio
TR	Technical Report
UNE	Una Norma Espanola
UV	Ultra Violet (light) (10 – 380 nm)

9.2. DEFINITIONS

Polyethylene (PE) - Polyethylene is probably the polymer seen most in daily life. It is one of the polymers called polyolefins. It has a very simple structure, the simplest of all commercial polymers. A molecule of polyethylene is nothing more than a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom. The following picture illustrates linear polyethylene, only with the chain of carbon atoms being many thousands of atoms long.

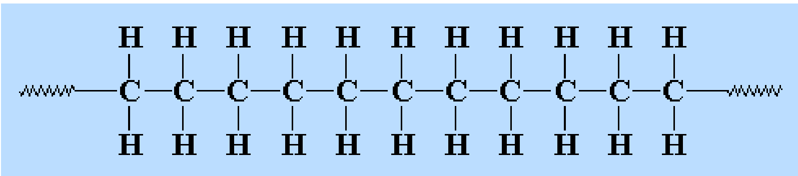

Figure 66: Polyethylene chain

High Density Polyethylene (HDPE) – HDPE is called linear polyethylene as the carbon atoms have only hydrogen atoms attached to them. This is much stronger than other forms of polyethylene which have branches of polyethylene attached to each carbon atom and which are cheaper to manufacture.

Low Density Polyethylene (LDPE) LDPE polyethylene is not as strong as high density polyethylene and is less costly to manufacture. It has a different structure which reduces strength. Some of the carbon atoms, instead of having hydrogens attached to them, will have long chains or branches of polyethylene attached to them. This is called branched, or low-density polyethylene.

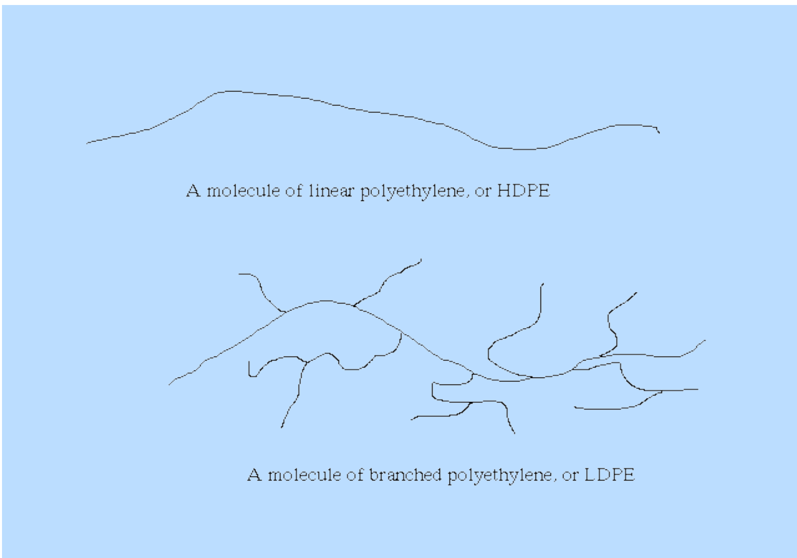

Figure 67: Linear and branched polyethylene chain

Linear low-density polyethylene (LLDPE) is a substantially linear polymer polyethylene with significant numbers of short branches. Linear low-density polyethylene differs structurally from conventional low-density polyethylene (LDPE) because of the absence of long chain branching. The linearity of LLDPE results from the different manufacturing processes of LLDPE and LDPE.

Medium density polyethylene (MDPE) may be preferred over LDPE for many applications requiring strength or stiffness in addition to ease of processing. MDPE is characterised by fewer and shorter side chains than LDPE.

Glass Reinforced Plastic (GRP) is a composite material. It is a fibre-reinforced polymer made of a plastic reinforced by fine fibres made of glass. It is stronger than many metals (when compared by weight), and can be moulded into complex shapes. The plastic matrix is usually a thermoset polymer such as epoxy or polyester resin, or it may be a thermoplastic.

Polyurethane Foam is a polymer composed of organic units joined by carbamate (urethane) links. Polyurethane polymers are traditionally and most commonly formed by reacting a di- or poly-isocyanate with a polyol. Polyurethane foam can be made using small amounts of blowing agents to give less dense foam providing better cushioning/energy absorption or thermal insulation.

Expanded Polystyrene Foam is a rigid and tough, closed-cell foam with a normal density range of 11 to 32 kg/m^3. It is usually white and made of pre-expanded polystyrene beads that are fused together in a final expansion phase using steam to provide heat and pressure

Elastomer Coating. An elastomer is essentially a polymer that displays properties of elasticity. They are made of carbon, hydrogen, oxygen and/or silicon. Elastomers are polymers that have viscoelasticity, this means they have both viscosity and elasticity, and very low inter-molecular forces which mean they have low elastic modulus. At room temperature, elastomers are soft and deformable. An elastomer coating can be used to seal, work as an adhesive, or to protect flexible objects.

The polymers molecular structure is set out in such a way that when it is stretched it may return to its normal state. The flexibility that an elastomer can offer is around 5-700% depending on the specific elastomer created. If the elastomer had short chains or no cross-links, the structure would not have the elastic properties and any deformation would be permanent. When elastomers are cooled they have less elastic properties, as the mobile chains reduce.

Ionomer Foam. A copolymer of ethylene and methacrylic acid typically used as a coating and packaging material. It can also be extruded as a continuous sheet of foam with a closed-cell structure. Foam density, cell structure, and sheet thickness can be varied as required within certain physical limits. Different sheet widths are achieved by varying extruder heads. Multiple-layer sheets can be created using heat to create rolls and cylinders.

Closed Cell Foam. A foam where at least 90% of the tiny cells of the foam are completely closed. This contrasts with “Open Cell Foam” where the tiny cells are broken and air or water will fill the “open” space inside the material. Closed cell foams will absorb a small percentage of water, the water absorption varies depending on the type of foam.

10. REFERENCES

- IALA NAVGUIDE
- IALA Recommendation R0106 (E-106) on Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System;
- IALA Recommendation R0108 (E-108) on Surface Colours Used as Visual Signals on Marine Aids to Navigation;
- IALA Recommendation A-126 on the Use of the Automatic Identification System (AIS) in Marine Aids to Navigation Services;
- IALA Guideline G1008 on Remote Control and Monitoring of Aids to Navigation;
- IALA Guideline G1010 on Racon Range Performance;
- IALA Guideline G1036 on Environmental Management in Aids to Navigation;
- IALA Guideline G1047 on Cost Comparison Methodology of Buoy Technologies;
- IALA Guideline G1064 on Integrated Power System Lanterns;
- IALA Guideline G1077 on Maintenance of Aids to Navigation;
- IALA Guideline G1094 on Daymarks for Aids to Navigation;
- IALA Guideline G1098 on The Application of AIS - AtoN on buoys;
- IALA Guideline G1099 on The Hydrostatic design of buoys;
- IALA Guideline G1108 on The Challenges of Providing AtoN Services in Polar Regions;
- IALA Guideline G1134 on Surface Colours used as Visual Signals on AtoN
- The IALA NAVGUIDE;
- IALA Guideline G1136 on Providing AtoN Services in Extremely Hot and Humid Climates;
- Report of the IALA Workshop On Challenges of Providing AtoN Services in Polar Regions 2013;
- ASTM G155 Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials;
- ISO 4582: 2017 Plastics - determination of changes in colour and variations in properties after exposure to glass-filtered solar radiation, natural weathering or laboratory radiation sources;
- ISO 4892 (1-4) Plastics - methods of exposure to laboratory light sources;
- ISO 9001 Quality management;
- EN 16472 Plastics - method for artificial accelerated photo-ageing using medium pressure mercury vapour lamps;
- ASTM D2244 - 16 Standard practice for calculation of colour tolerances and colour differences from instrumentally measured colour coordinates;
- ASTM D2565 - 16 Standard Practice for Xenon Arc Exposure of Plastics Intended for Outdoor Applications;
- ISO 1664-4 Colorimetric evaluation of colour coordinates and colour differences according to the approximately uniform CIELAB colour space;

- ISO 1183 Plastics - methods for determining the density of non-cellular plastics;
- ASTM D-4883 Standard test method for density of polyethylene by the ultrasound technique;
- ASTM D-1505 Standard test method for density of plastics by the density-gradient technique;
- BS 4370 Methods of test for rigid cellular materials;
- DIN 53505 Testing of rubber - shore a and shore d hardness test;
- DIN EN ISO 527-1 Plastics - determination of tensile properties - part 1: general principles;
- DIN EN ISO 527-2 Plastics - determination of tensile properties - part 2: test conditions for moulding and extrusion plastics;
- DIN 53516 Testing of rubber and elastomers; determination of abrasion resistance;
- ISO 6603-2 Plastics - determination of puncture impact behaviour of rigid plastics - part 2: instrumented impact testing;
- DIN EN ISO 6383-1 Plastics - film and sheeting - determination of tear resistance - part 1: trouser tear method;
- EN 1931 Flexible sheets for waterproofing - bitumen, plastic and rubber sheets for roof waterproofing - determination of water vapour transmission properties;
- EOTA TR008 Determination of the resistance to fatigue movement;
- EN 12201-1 Plastics piping systems for water supply Polyethylene (PE). Part 2: Pipes;
- EN ISO 1133 Plastics – Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics (ISO 1133:1997);
- EN ISO 2505 Thermoplastics pipes, longitudinal reversion, test method and parameters (ISO 2505:2005);
- EN ISO 3126 Plastics piping systems – Plastics piping components – Measurement and determination of dimensions;
- EN ISO 6259-1 Thermoplastics pipes. Determination of tensile properties. Part 1: General test method (ISO 6259-1:1997);
- EN ISO 13920 Welding- General tolerances for welded constructions – Dimensions for length and angles shape and position;
- ISO 6259-3 Thermoplastics pipes – Determination of tensile properties – Part 3: Polyolefin pipes;
- ISO 13953 Polyethylene (PE) pipes and fittings – Determination of the tensile strength and failure mode of test pieces from a butt-fused joint;
- ISO 16770 Plastics – Determination of environmental stress cracking (ESC) of polyethylene – Full-notch creep test (FNCT);
- ISO/TR 10358 Plastics pipes and fittings – Combined chemical-resistance-classification table;
- ASTM D1929-16 Standard test method for determining ignition temperature of plastics;
- DIN 54836 Testing of combustible materials; determination of ignition temperature.

ANNEX A ADVANTAGES AND DISADVANTAGES OF PLASTIC BUOYS

ADVANTAGES

- Plastic does not corrode.
- It is easier to maintain: only removal of marine growth, no painting for plastic parts required.
- There is less maintenance on shore for the plastic components (no grit blasting, no painting with the exception of GRP). Therefore, less resources may be utilized.
- Plastic buoys are of lower weight (1/2 to 1/3 mass of the equivalent diameter steel buoys). Therefore maintenance may be able to use smaller buoy tenders.
- The whole life costs may be less than steel buoys, see also IALA Guideline G1047 on Cost Comparison Methodology of Buoy Technologies.
- Since the 1980´s plastic buoys have been operated successfully.
- There are a number of commercial companies offering plastic buoys.
- Most plastic is recyclable.
- Where plastic buoys are of modular construction, it is possible to change individual parts or segments if they are damaged or need refurbishment.
- Large modular buoys are easier to transport and store, as parts can be disassembled for transport.
- The number of spare parts (whole buoys held) can be reduced.
- It is possible to encase a radar reflector within a plastic buoy's superstructure.

DISADVANTAGES

- It is more difficult to change the colour of a plastic buoy, as conventional painting is not reliable for plastic surfaces.
- Generally plastic buoys have a shorter lifetime than steel buoys.
- Plastic buoy components will be specific to each manufacturer and may therefore not be interchangeable.