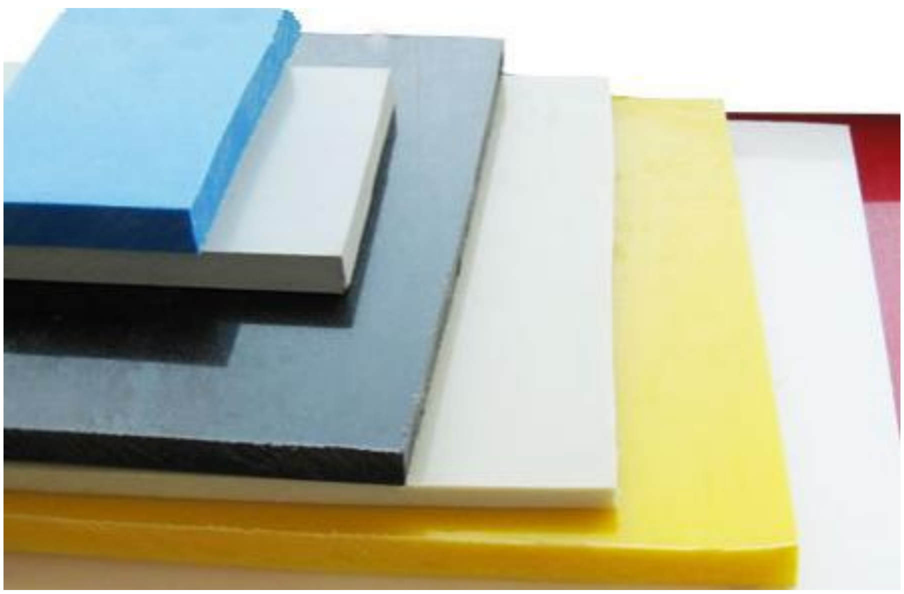
High Density Polyethylene (HDPE)

As a Marine Material



Written by: Tobias Clarke

Introduction

In the marine industry and all areas of life, engineers and designers are always looking for a better/different material to use. High Density Polyethylene or HDPE is growing in popularity in the marine sector but because it is relatively new to structural applications there is a general lack of information about HDPE.

Background

Before the 1950's the only polyethylene was a low density material but with an advance in the manufacturing process it was possible to create a material with a higher density that had a higher chemical resistance, harder, more opaque than before, and more importantly a higher specific strength. This new material, HDPE, has a density of between 0.93 and 0.97 g/cm^3, slightly lighter than water. There are two main uses, the first is in blow moulding, used to make items such as plastic bottles and the other area where it has been extensively used is in piping. Both of these take advantage of its resistance to chemicals and to the fact that it does not rot or corrode.

Material Properties

The main engineering properties are given in Table 1, with aluminium given as a reference material. Figure 1 gives a stress strain curve from material testing of HDPE.

Property	Units	HDPE PE100	Aluminium 5086 H116
Density	g/cm^3	0.93-0.965	2.66
Young's Modulus Modulus of Elasticity	MPa (N/mm^2)	786	70,000
Tensile Strength (yield)	Mpa	24.5	380
0.2% Yield Strength	Mpa	15.7	
Poisson's Ratio		0.38	0.33
Operating Range	^{0}C	-30-85	
Melting Point	^{0}C	130	660

Table 1: Material properties for HDPE & Aluminium

Because of its inert nature HDPE is resistant to most chemicals that are commonly used, because of this it is considered a food grade material. When HDPE is used in the marine environment that translates to being able to be used for fuel tanks, waste tanks, tanks for most chemicals. Importantly it does not need to be given an antifoul coating as marine growth cannot penetrate the surface to strongly adhere to it, so all it takes to remove barnacles and the like is a high pressure wash.

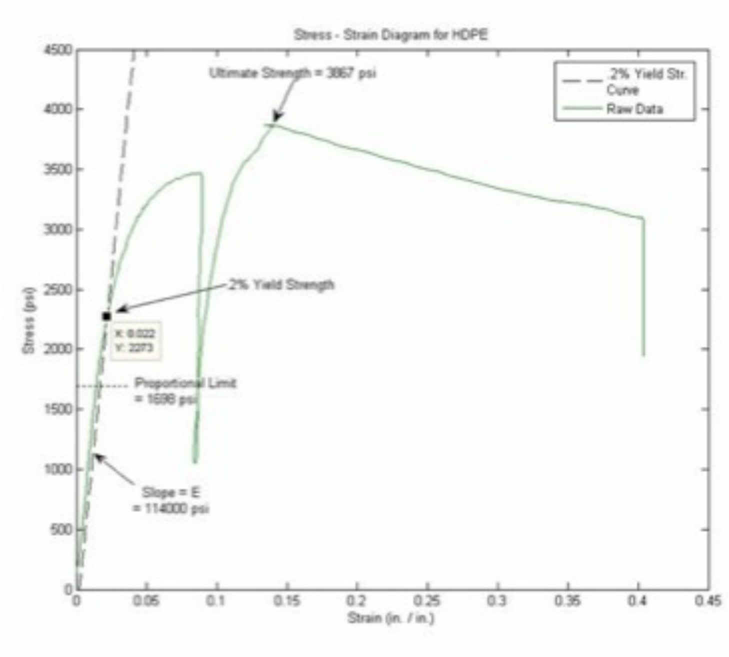


Figure 1: Stress-Strain Diagram for HDPE

Failure Mode

Unlike aluminium, which is the most common marine boat building material, the behaviour of HDPE as it nears failure is substantially different to most other materials. The percentage of elongation before complete failure is over 180%, which means that it is very rare for the material to totally fail but will continue yielding.

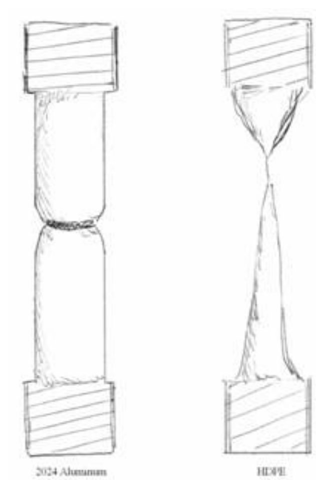


Figure 2: Failure mode for HDPE & Aluminium

Engineering Issues

Like all materials there are particular items that need to be considered during design and construction. The main areas of HDPE are listed below:

High thermal expansion

Unlike other materials HDPE has a large degree of thermal expansion. This is particularly important to be aware of during the assembly stage as if material is cut at a significantly different temperature to other components issues may arise with fitting the assembled pieces. The rate of expansion is four to five higher than that of Aluminium ($120*10^{-6}$ compared to $24*10^{-6}/\,^{0}C$ for Aluminium). A rule of thumb for expansion is given below

$$expansion\ (mm) = 0.2 * length\ (m) * temperature\ change$$ (Celcious)

Weld inspection

One potential problem with HDPE compared to either steel or aluminium is that it is impossible to check the quality of a weld with conventional methods such as X-ray or die testing. This possesses a problem when it is critical to make sure the weld is waterproof or has no internal defects. The only way to make sure the weld has taken to both surfaces is to insert a copper wire or similar behind the weld and perform a spark test post weld. This method shows any microscopic gaps that could prove a problem with structural strength or watertight integrity.

High Deflection

When using HDPE in design it is not usual for the stress to be the limiting factor as opposed to the deflection amount. If the situation allows for additional deflection above what is normally allowed then the thickness of the HDPE can drastically reduced.

Structural Comparison

Looking at two similar situations where a plate needs to be stiffened, for example a hull bottom, as shown in Figure 3 allows us to compare the relative weights of HDPE and aluminium, as calculated in Table 2.

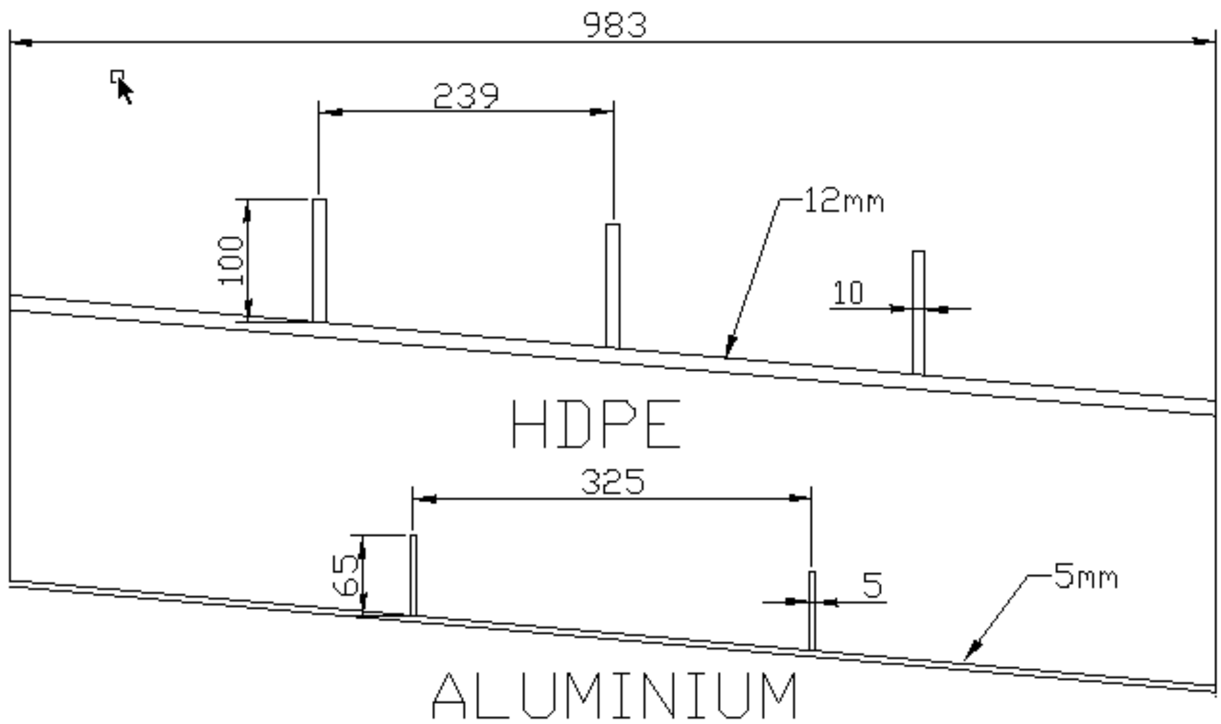


Figure 3: hull bottom structure

		HDPE	Ali
Frame Spacing	mm	600	600
Hull Bottom	mm	12	5
Width	mm	986	986
No. of stiffeners		3	2
Stiffener height	mm	100	65
Stiffener thickness	mm	10	5
Density	g/cm^3	0.996	2.66
Weight per meter	kg/m	14.8	14.8

Table 2: Weight per meter calculations

Looking at this comparison it can be seen that even with the extra thickness of material in a HDPE construction there is no difference in the final weight per meter of either material. It is also worth noting that in this calculation, it was the deflection governing the stiffener spacing on HDPE and stress in aluminium, so in the case of an extreme load situation the aluminium will exceed the design stress and start to fatigue fracture, where the HDPE structure will exceed deflection limits but return to its original condition without detrition.

Environmental

HDPE in many regards is a better material to use than aluminium or steel in the marine environment because it does not need painting or antifouling which reduces the pollutants into the water. Because of its chemical composition it is not harmful to human or animals if consumed or inhaled during construction unlike aluminium or fibreglass. HDPE has an "eco indicator 95" of 2.8mPt, while aluminium has a value of 56.3mPt, the "eco indicator 95" is a method used to look at the production and life cost of materials, where the lower the value the lower the environmental impact. The energy required to manufacture 1kg of HDPE is 81Mj/kg compared with aluminium at over 200mj/kg.

Machinability

HDPE is a material that is an easy to build with tools such as jigsaws, drills, electric planes, CNC cutters, and other basic manufacturing tools is all that is needed to cut and shape HDPE. To weld HDPE a hot air extrusion gun is used to preheat the material and add a melted stream of plastic as the weld.

Figure 4: Hot air gun

Summary

The structural values alone do not show the real benefits of HDPE as a material for the marine environment, but the lack of corrosion and the ease the material is used the benefits become apparent.

References

http://www.ineos-op.com/media/files/other_tech_info/Typical%20Engineering%20Properties%20of%20HDPE.pdf

www.gfpiping.com/ActiveContent/PE100-TechHandbook-PDF.pdf

www.matbase.com/material/polymers/commodity/hdpe/properties

http://www.jland.org/swat/e6/tensile/

http://www.matbase.com/material/non-ferrous-metals/wrought-aluminium/al99.5-1050/properties

http://www.borealisgroup.com/pdf/chemical-resistance/chemical-resistance-hdpe-ld.pdf

http://www.sdplastics.com/polyeth.html

http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma5086h34

http://www.matweb.com/search/DataSheet.aspx?MatGUID=c35a0a3e740e424fad260a5da2c2b50a&ckck=1