# THE USE OF PLASTICS AND POLYMERIC PRODUCTS IN CONSTRUCTION OF ROVs AND AUVs

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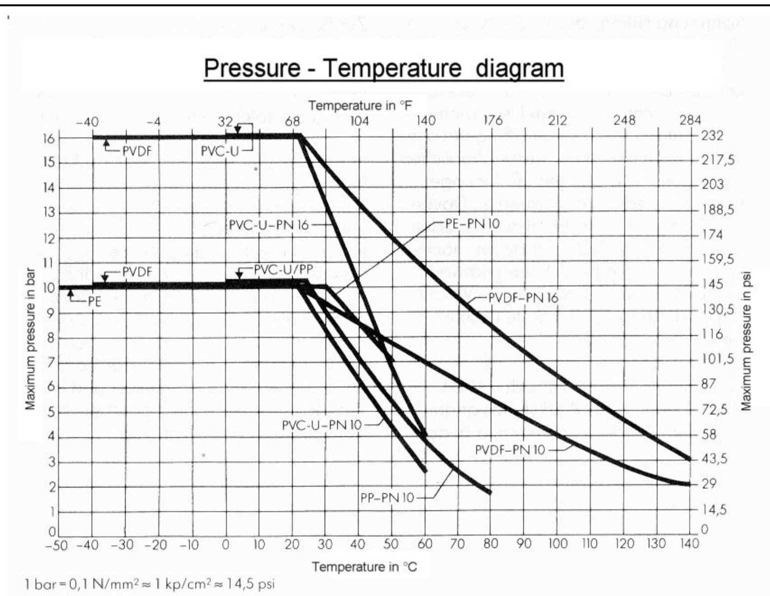
## Introduction

In 1937, PVC-U tubes for the distribution of drinking water were installed in the town of Hamburg,Germany.Until a few years ago they were still in use.Waterpressure in those tubes varied from four to six bar (59-88psi) and all connections were glued.After all those years of continuous service no signs of cracks or aging appeared.At present,PVC,next to polyethylene is the most frequently used plastic in industry as well as in the household.




That was the major reason to start thinking about the use of these materials in construction of underwater vehicles,and to create Subsea Robotics,an institute that specialises in research and development of building techniques in plastic.

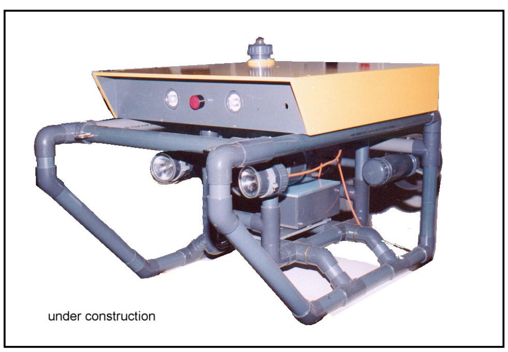
One of the major advantages of these products is the total resistance to corrosion.Due to it’s anti-magnetic properties it can be used in military operations. Also because thermoplasts have no remanence for radiation,they can be used in radiation-contaminated areas.

As for pressure resistance,the same conditions are valid as for metals,and

wall thickness can be calculated by the use of wall thickness/tube diameter tables.
One has to keep in mind that physical resistance can degrade with ambient temperature changes,depending on the kind of plastic used.
Because fresh and seawater temperatures can vary from about 0 to20°C (32 – 68° F) there is almost no variation in physical properties of most of the thermoplasts.
According to the use and the prevailing temperatures of the locations,there is a choice in construction materials for underwater vehicles such as; PVC,PP,PE,PVDF,etc.

There are two major construction principles for underwater vehicles,open or closed structures.

Open structure involves the building of a skeleton frame out of tubes or fraised out of plastic plates,wherein all pressure-tight components are located.
Closed structure involves a massive pressure-tight body where all components are located within.The only visible external components are the electric thrusters,lights and tracking system.
A combination of both structures is chosen for,where more substantial vehicles are involved (see picture)These can be finished with a protective outer fairing,favorable for hydrodynamic resistance.
The advantage of skeleton frames is such that a considerable gain of weight is obtained and the modular build-up of components enables a quick change or repair.




**Specific properties of some of the most frequently used thermoplasts**
**Polyvinylchloride**

Better known as PVC,polyvinylchloride is one of the oldest and most used plastics out of the family of thermoplasts.
PVC can be glued,welded,and can,by applying heat be casted or pressed into a mould.PVC waste can be recycled and re-use is possible.
PVC is formed by polymerization of vinylchloride,a gaseous monomer. Certain products can be added such as plasticizers,color pigments and fillers.But for use in underwater vehicle construction PVC-U(unplastisized) is used with dark grey color pigment RAL 7011
Only parts that need to be extruded or formed via casting techniques need PVC mixed with stabilizers and emulgators.The total of added products is not to exceed 5% to guarantee the physical properties of the plastic.
To enforce resistance against heat and UV radiation metallic stabilizers are added(Zinc).PVC-U is resistant to most acids,bases and salts.
The most important physical properties of this widely used and cost friendly plastic are listed below.

| PROPERTIES | VALUES | UNIT |
|---|---|---|
| DENSITY | 1.38 | G/cm3 |
| TENSILE STRENGHT | 55 | N/mm2 |
| BREAK LOAD | >30 | % |
| RESISTANCE TO IMPACT | NO BREAK | KJ/m2(23°C) |
| ELASTICITY MODULE | 3000 | N/mm2 |
| EXTENSION COEFFICIENT | 0 .08 | mm/m°C |
| MAX.OPERATING TEMP. | 60 | °C |
| VICAT PLASTICITY TEMP. | >76 | °C(VST/B 50) |
| WATER ABSORPT ION | >4 | mg/cm3 |
| SURFACE RESISTANCE | ca $10^{13}$ | Ohm |

Functionality and service life depend greatly upon the choice and pressure resistance of the thermoplast.The most important factors are;maximum pressure,temperature and exposed time.The pressure/temperature diagram on the previous page shows the physical stability of various thermoplasts.The values of that diagram are calculated for a service time of 25 years with a built in safety factor of 2. 5 (PVC-U)

**Electrical resistance**

Plastics such as PVC,PP,PE and PVDF are part of the non-conductive materials.Non-conductors are these that have a specific resistance higher than $10^{6}$ Ω.cm.As all above-mentioned plastics have a specific resistance of about $10^{15}$Ω.cm none of them are electrical conductors.But when the resistance value of solids exceeds $10^{9}$Ω.cm,they become sensitive to electrostatic loads.We have to take this into consideration,because when an electrostatic load builds up on the inner surface of a pressure tight container,it can be devastating for chips and integrated circuits.So it is advised to coat the inside of plastic tubes with an antistatic layer,or to make a conductive connection between the inside and the outside surface as to evacuate all possible charges to the surrounding water.

**Coefficient of expansion**

When building larger constructions out of plastics we have to keep in mind that the coefficient of expansion is more important than the one for metals.To avoid stress in the material we can calculate the expansion rate with following formula;

$\Delta L : L \,.\, \Delta T \,.\, \delta$

ΔL: expansion in mm
L : length of the part in m.
ΔT: difference between min and max temp. in °C
δ : coefficient of expansion (PVC-U=0.08 mm/m°C)

**Test Pressure**

Test pressures for PVC-U structures are applied according to the values of the following diagram;

| PN | PT |
|---|---|
| ≤ 10 bar | PN . 1.5 |
| > 10 bar | PN + 5 bar |

**Polypropylene**

Polypropylene is a thermoplast out of the group of the polyoleofins.It has a partially cristalline structure and has a smaller density than the other thermoplasts.The physical properties,chemical resistance and most of all the resistance to high temperatures make that kind of plastic suitable for industrial use.PP is formed by polymerization of propylene ($C_3H_6$) while adding catalysts.Three different types are available in tube format,PP homopolymer,PP copolymer and PP random copolymerisat.PP homopolymeris mostly applied in

construction of fittings and armatures because of its favorable time/resistance curve.PP copolymer is resistant to extreme low temperatures where PP random copolymerisat in contrast is resistant to high temperatures.
PP is not very resistant to UV rays and has to be protected from those by shielding or coating with a UV absorbing paint.PP is part of the non-polar substances which means that it's surface is not soluble by any solvent so it cannot be glued but welding by hot gas,IR or ultrasonics is no problem.The physical properties of polypropylene are shown in the diagram.

| PROPERTIES | VALUE | UNIT |
|---|---|---|
| DENSITY | 0,915 | g/cm3 |
| MELT INDEX | 0,5 | g/10 min |
| TENSILE STRENGHT | 33 | N/mm2 |
| ELASTICITY MODULE | 1100 | N/mm2 |
| RESISTANCE TO IMPACT | no burst | mJ/mm2 |
| MELTING TEMP. | 160-165 | °C |
| EXTENSION COEFFICIENT | 0,15 | mm/m°C |
| HEAT CONDUCTIVITY AT 20°C(68°F) | 0,22 | W/m.K |
| SURFACE RESISTANCE | $>10^{13}$ | Ω |

**Polyethylene**

Polyethylene or PE is one of the most well known plastics..PE medium (PE-MD) or high (PE-HD) density is used for the construction of tubes.PE is a classic representative for the polyoleofins with formula; - $(CH_2 – CH_2)$ n. suitable for many purposes due to it's low density,great flexibility and resistance to bursting.Like PP,PE belongs to the cristalline structures and can,after polymerization,no longer be glued or re-chaped by heat .So like PP it has to be welded by hot gas,IR or ultrasonics.
The physical properties of PE are listed in next diagram.

| PROPERTIES | VALUE | UNIT |
|---|---|---|
| DENSITY | > 0,93 | g/cm3 |
| MELT INDEX | 0,4-1,3 | g/10 min |
| TENSILE STRENGHT | 22 | N/mm2 |
| ELASTICITY MODULE | 800 | N/mm2 |
| RESISTANCE TO IMPACT | no burst | mJ/mm2 |
| MELTING TEMP. | 127-131 | °C |
| EXTENSION COEFFICIENT | 0,20 | mm/m°C |
| HEAT CONDUCTIVITY AT 20°C | 0,43 | W/m.K |
| SURFACE RESISTANCE | > $10^{13}$ | Ω |

**Polyvinylidenfluoride**

Polyvinylidenfluoride or PVDF is a cristalline thermoplast with high mechanical,chemical and physical resistance.
Due to its high cristalline structure PVDF has a long service time and a high thermal stability.
PVDF is very resistant to UV and Gamma radiation so it can be used in radiation contaminated environments.
The physical properties of PVDF are shown in next diagram;

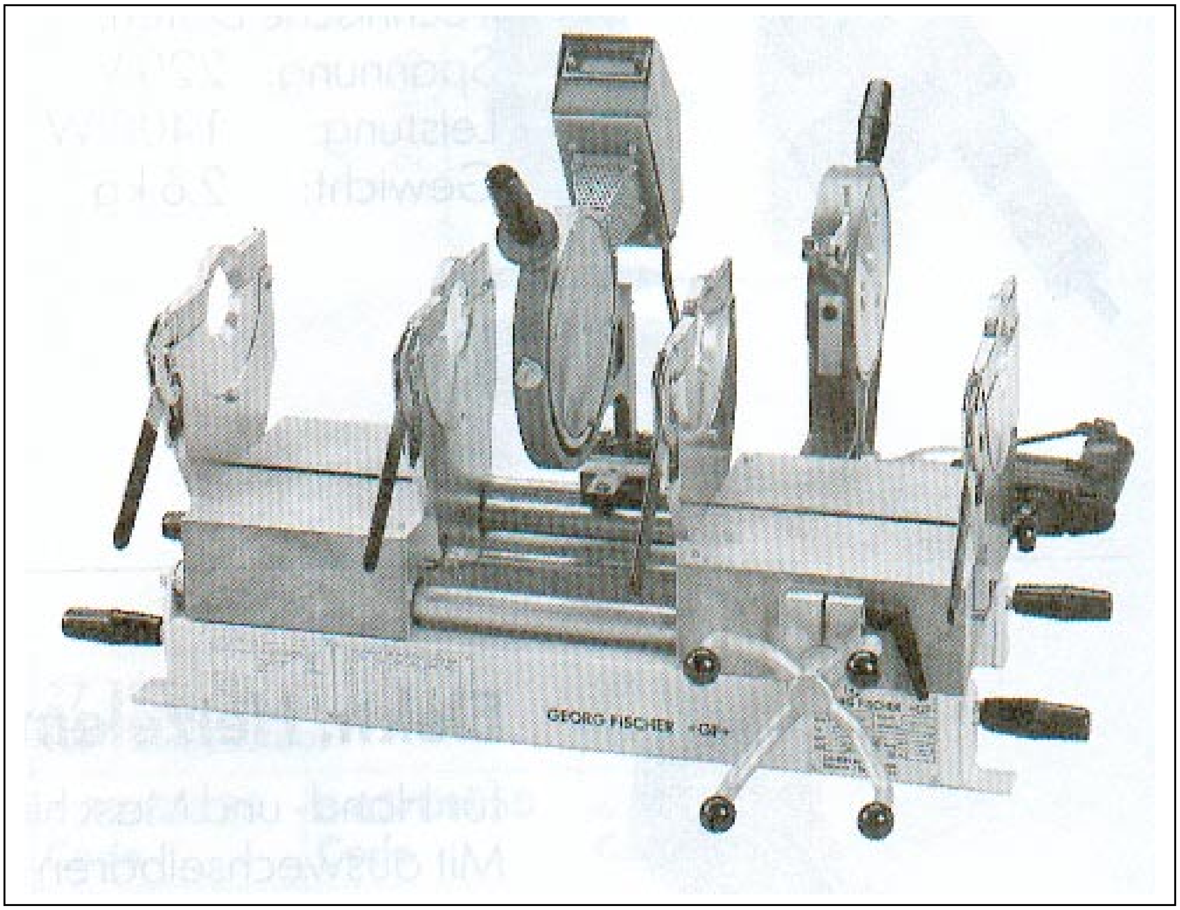
| PROPERTIES | VALUE | UNIT |
|---|---|---|
| DENSITY | 1,78 | g/cm3 |
| TENSILE STRENGHT | 54 | N/mm2 |
| BREAK LOAD | 80 | % |
| ELASTICITY MODULE | 2400 | N/mm2 |
| VICAT PLASTICITY TEMP. | 142 | °C |
| HEAT CONDUCTIVITY | 0,19 | W/K.m |
| SURFACE RESISTANCE | $10^{13}$ | Ω |

**Machining techniques**

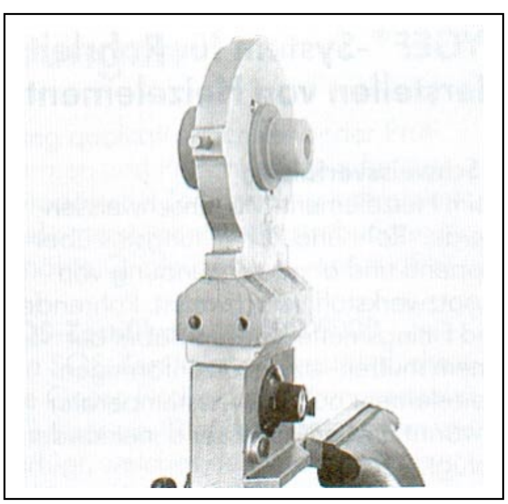
Working these plastics is more or less equal to working metals.Most thermoplasts can be sawed,drilled,fraised,etc.Joining by cold or hot welding needs some attention though.From all mensioned thermoplasts only PVC can be cold welded or glued.This is possible because PVC surfaces can be made plastic by applying solvents and when put together under pressure,molecules tend to flow over each other thus creating a homogeneous bond.For all other plastics hot welding has to be used.There are a few possibilities in welding plastics;hot gas welding,mirror welding and electro welding or ELGEF system.
Two recent technologies in plastic welding are HF welding and ultrasonic welding.

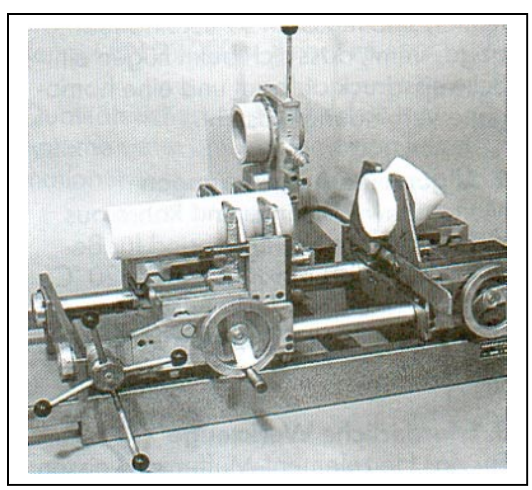
Hot gas welding is the proper way for joining irregular shaped parts in various angles.The welding device consists of a welding pistol with a nozzle through wich a hot gas is blown with ajustable temperature and flow.The nozzle can be changed according to the type of welding and thickness of the material.The welding wire is applied manually or automatically when using a speed-welding nozzle.The welding surfaces have to be fraised in V,K or X shape.
It is advised to create a counter welding on the opposite of the welded part to increase strenght and homogeneousness.
Mirror welding is used for joining tubes.The two surfaces are heated simultaneously by pressing them on either side of a heated metal plate.When enough material has become plastic the heating plate is removed and the two

tubes are pressed together and left to cool down.An example of an automatic Mirror-welding device is shown in the picture below.

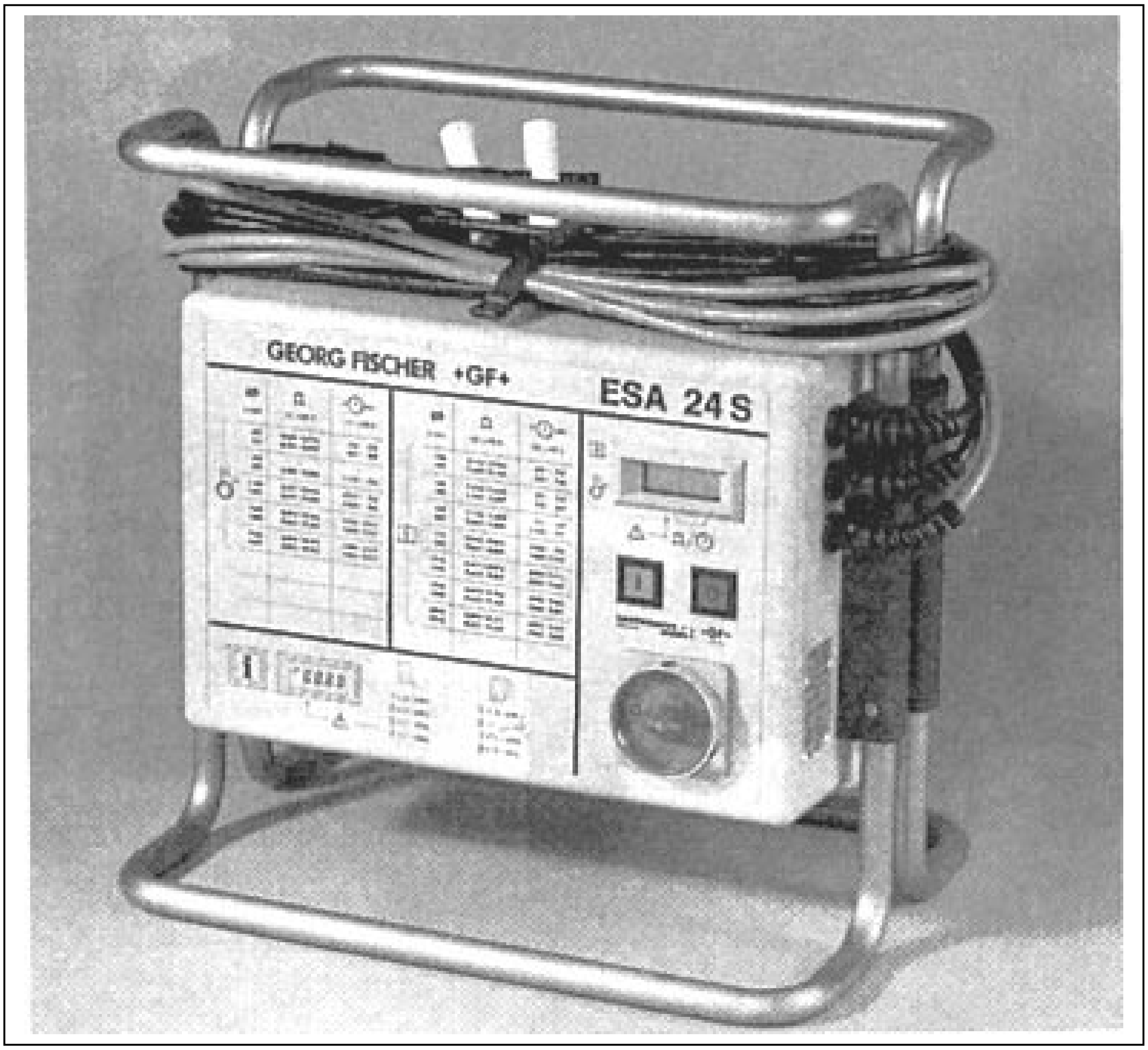



Socket welding is a variant to mirror welding whereby a tube is welded into a socket.The tube insert and the socket are heated via a specially shaped welding stamp and are pressed together  when plasticity temperature is reached.



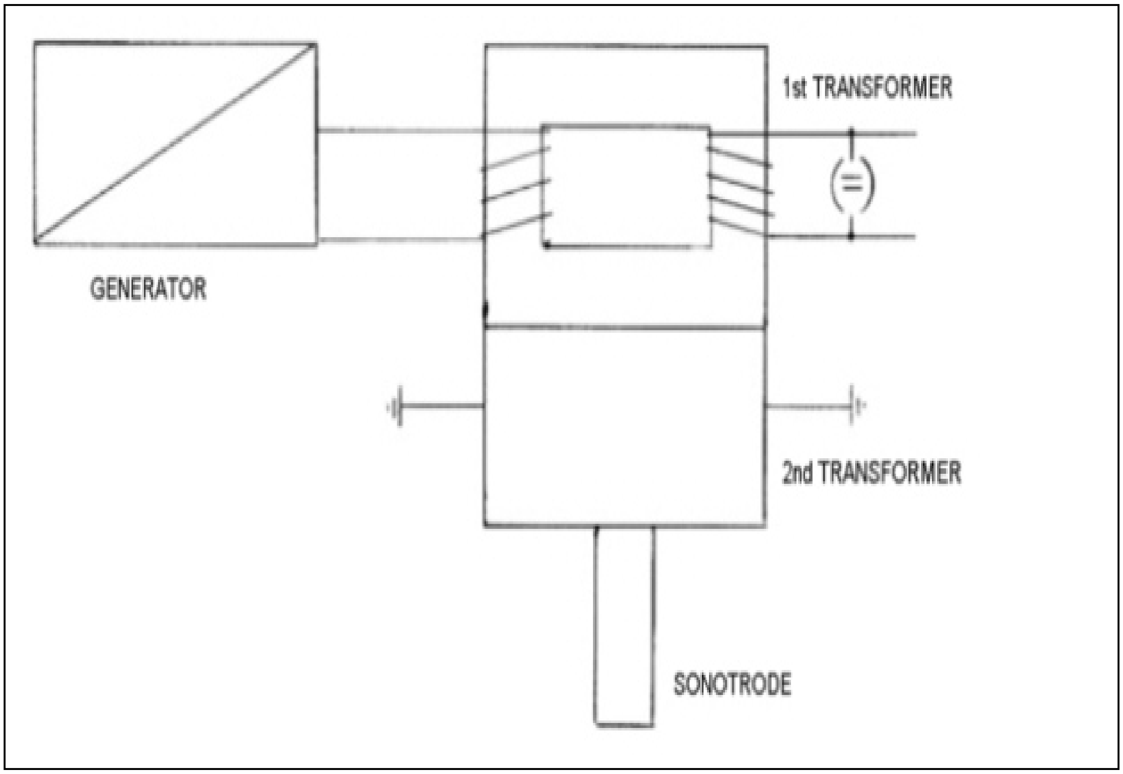


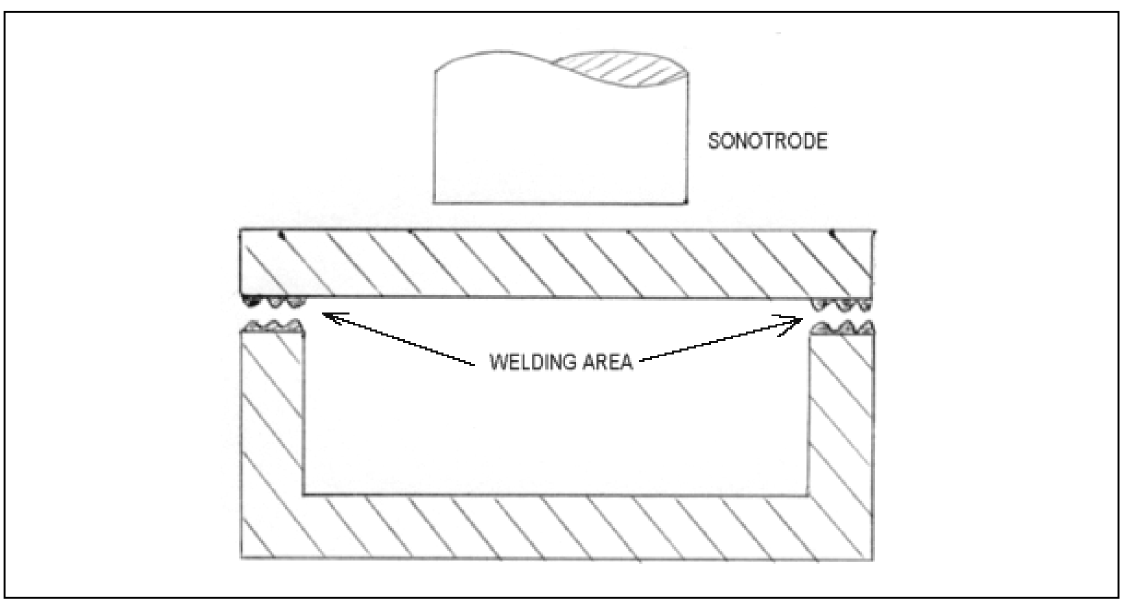
A related system to socket welding is electro welding or ELGEF system.Tube and socket are pressed together first and then electric current is applied to a resistance build into the socket.That resistance creates enough heat to melt the two parts together.The advantage of that system is that it can be executed on the spot.



HF Welding is a process whereby high frequency electrical energy is converted into heat,enough to create plasticity of the parts to be welded.The welding electrodes are used to press the parts together while HF energy is fed.

Ultrasonic welding is a recent development in welding technology.Heat is produced in an electromagnetic way and by means of double energy shift transferred into the plastic.
High frequency energy is transformed into mechanical energy.That energy is being changed into an ultrasonic vibration and fed to a sonotrode.The sonothode is placed right above the parts to be welded and the vibration that spreads through the material generates enough heat to establish the welding.



**Building technologies for the future**

Building techniques for underwater vehicles haven't changed much since men's first efforts to explore the sea. Most of the underwater vehicles are built according to classic hydrodynamic principles and still use electric propulsion,rudders and ballast tanks to move through the water.
Due to my experience in aeronautics I started working from another point of vue,notably from aerodynamics.Underwater vehicles are like airplanes,moving around in a 3-dimensional world with the only difference being the density of the medium.By taking examples from flight technology,we can eliminate a complex construction of ballast regulation and heading changes simply by the use of a hydrodynamic wing with variable profile.By altering the wing shape we can induct or avoid lift on the extrados or intrados of the wing,creating a horizontal movement up or down,without altering the underwater  weight of the vehicle.This is an easy process because vehicles like ROVs or AUVs tend to have a fixed surface weight once all components are installed and neutral boyancy has been trimmed for.The change in lift capacity can simply be obtained by changing the wing profile on the upper or lower side in combination with speed changes.It is at that point that thermoplastic building materials are very useful.It is possible,by means of a flexible wing covering,to change the hydrodynamic shape by blowing or vacuuming the cavity underneath.This could be achieved by using hydraulics because there are no compression problems in fluids.It is a rather simple system that requires few parts,has a reliable cerviceability and cuts down the building costs.The same system can be applied to rudders,responsible for movement around the top axis and longitudinal axis.
Rudder and ailerons can be combined into an inverted V shaped tail section whereby a combination of profile changes can result in a single or combined movement around those axes.
Extensive research on the hydrodynamic flexible wing profile has been done at Subsea robotics and a first working prototype is to be presented next year.

**References**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