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ADVANCED MATERIALS FOR SUBMARINE CONSTRUCTION

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Advanced Materials for Submarine Construction

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Advanced Materials for Submarine Construction

As a class of vessel, submarines are used in a wide variety of applications. The most familiar roles include:

- covert attack of enemy shipping using torpedoes to isolate or blockade a given area.
- a platform for strategic nuclear weapons.
- hunter/killer of enemy submarines.
- a platform for delivery of personnel and/or equipment into enemy territory to conduct covert operations.
- seeking and destroying undersea explosive mines.

These applications can be categorised into a number of distinct groups by means of size of vessel, whether manned or unmanned, by required operating depth and by mission profile (e.g. speed, manoeuvrability, payload, rate of dive/surfacing, fatigue life expectation).

A platform for strategic nuclear weapons. These are large (in excess of 15,000 tons) and manned (a crew complement in excess of 100. A typical mission profile is to have the ability to cruise at relatively high speed then to remain stealthy by being submerged for long periods (months), at depth.

An oceanographic research vessel. This may be small (around 1 ton), unmanned, and with a deep diving (in excess of 4000 metres) capability. A typical mission profile might be to survey areas of the ocean floor (perhaps 10 km by 10 km) at very low speed whilst in an autonomous mode from the supply vessel for, perhaps, 20 hours.

Pressure Hull Materials

From a hull design viewpoint, these represent two quite different situations. In the former, minimising the internal volume is not the principal driver and that, coupled with the depth/mission requirements, leads to a hull design dictated by **buckling resistance**. In the latter example, the relationship between internal volume, payload mass, power supply mass/volume and vessel cross section (ie drag resistance) is critical, as it dictates the length

of mission which can be achieved. This can lead to a hull design which is dictated by **crushing resistance.**

Materials Selection.

The design requirements of high buckling resistance and/or high crush resistance translate to key material requirements of **high Young's modulus** and **high compressive strength**. Based on availability, ease of fabrication, low cost and its historical usage in ship building, steel is the baseline material for submarine hull construction. A comparison of the specific Young's moduli of a range of engineering materials shows that most materials (including steels) have a similar value whereas aramid reinforced plastic and carbon fibre reinforced plastic materials offer significant improvements (more than a factor of five). A comparison of the specific compressive strength values for the same materials shows that most materials (including steels) have a similar value with the exception of Titanium alloy, glass fibre reinforced plastic and carbon fibre reinforced plastic materials, which all offer significant improvements. It should be noted that aramid reinforced plastics exhibit modest levels of compressive strength, discounting them from further consideration.
Thus, contending materials for submarine hulls are:

- steel
- Titanium alloy
- glass fibre reinforced plastics
- carbon fibre reinforced plastics

These are now considered in more detail below.

Steel

Steel has been the principal material used to date for submarine hull construction, based on availability, ease of fabrication, low cost and its historical usage in the general ship building industry. In the west, all large military submarines have utilised a ring stiffened, cylindrical, pressure hull configuration --both the rings and cylinder being fabricated from steel.

Advantages:

- readily available, cheap raw materials.
- well developed, reliable, fabrication process.
- steel has good fracture toughness which translates into good shock/blast resistance.

Disadvantages:

- ferromagnetic (hence raising the possibility of detection via magnetic signature).
- prone to corrosion.

There has been a major research effort to date investigating HSLA steels as a cost reduction exercise to replace the presently employed Q1N steels for submarine hull construction. These steels offer the potential of reduced material and fabrication costs through lower alloy element content and improved weldability requiring no weld preheat. Savings of the order of 10% of hull construction costs have been estimated, although these must be regarded as low since these costs relate to preheat only and no additional cost savings resulting in a more efficient process were not included.

Two generic types of HSLA steel are currently under evaluation. They derive their combinations of strength and toughness via two radically different alloying philosophies involving either the addition of Cu (HSLA100) or the addition of B (BIS812EMA). There has been a detailed programme to investigate the mechanical properties of these steels and their weldments. Work is now in hand to determine the stress corrosion susceptibility and low frequency corrosion fatigue crack growth behaviour.

Work on HSLA100 has shown that this steel is not susceptible to SSC at load levels close to or approaching the limit load under applied electrochemical potentials (AEP) ranging from -700 to -1100 mV SCE over the test duration of 1000 hours. Tests on samples at an AEP of -500 and -600 mV SCE (i.e. an AEP above the free corrosion potential) caused general anodic dissolution of the steel and although time dependent failure was observed this was attributed to general corrosion wastage of the bulk material.

However tests at -1200 mV SCE did show evidence of time dependent cracking at normalised load ratios Pa/PL in excess of 0.9.

A general summary of the corrosion fatigue performance is that at R=0 HSLA100 steel exhibit slightly faster fatigue crack growth rates than Q2N at the free corrosion potential.

Titanium Alloy

Titanium alloy has been considered by many military submarine designers, but has only been used for the purpose, in earnest, within the Former Soviet Union.

Advantages:

- better specific strength than steel.
- non-ferromagnetic (hence reducing the possibility of detection via magnetic signature).
- good corrosion resistance.

Disadvantages:

- hull fabrication is perceived to be difficult, due to complexities in welding Ti alloy.
- Ti alloy is relatively expensive (20 times that of steel), due relative scarcity (except in the Former Soviet Union).

Titanium alloys have been used in the construction of a number of smaller, specialist, submarines, where the performance advantages over steel are considered to be essential and justify the cost penalty.

Glass and Carbon Fibre Reinforced Plastics

Advantages:

- better specific strength (GRP, CFRP) and stiffness (CFRP) than steel.
- non-ferromagnetic (hence reducing the possibility of detection via magnetic signature).
- good corrosion resistance.
- potentially lower maintenance costs.
- stealth capability can be incorporated into the FRP during fabrication.

Disadvantages:

- a revolutionary hull fabrication route needs to be developed, well beyond current capabilities.
- basic materials costs for GRP are broadly equivalent to steel whilst CFRP is 15 times as expensive. Thus, overall fabrication costs, life cycle costs and improved operational envelope must be attractive drivers.

Glass fibre reinforced plastic materials are already well established in the marine sector. They are used in the fabrication of hulls and superstructures for a wide variety of vessels, from sailing yachts and passenger ferries, through to 80 metre long minehunters. The range of sea states likely to be encountered in service dictate that a surface ship hull must be designed to withstand a wide variety of in-plane and out of plane bending loads - a material with near -isotropic in-plane strength distribution is called for. At the bottom end of the market, this is achieved by applying the glass reinforcement and the resin, in a random distribution from a spray gun, in the form of short, chopped fibres. At the top end of the market, the reinforcement is applied in the form of a woven cloth (typically a coarse weave 0/90 arrangement) which is cut to fit the mould contours. Resin impregnation methods range from "bucket and brush" to the more sophisticated "SCRIMP" (Siemens Composite Resin Injection Moulding Process - a variant of resin transfer moulding using single-sided, low cost tooling which is suited to large, fairly flat geometry's). Low resin viscosity (to aid resin flow into the cloth) and long pot life (to avoid occurrence of cure before having the time to complete the impregnation) are essential attributes of the resin system. Due to the size of the parts, cold-cure thermosetting resin systems are used (either polyester, epoxy or vinyl-ester), to avoid the need for large post-cure ovens.

This level of technology will typically result in laminates with a near-isotropic in-plane Young's Modulus of 20-28 GPa and strength levels of 200-300 MPa. These values are sufficient for boat hulls, but they are rather uncompetitive for submersible hulls. However, the design of a submarine hull is driven by one principle load case -- withstanding the external hydrostatic pressure whilst at maximum dive depth. Since a submarine hull is essentially a closed ended cylinder, the external hydrostatic pressure results in an in-plane -2(hoop) : -1(axial) biaxial stress state acting in the hull wall. There is no need for a near-isotropic fibre arrangement and optimisation of the fibre placement geometry is therefore possible, making a more efficient use of the inherent fibre properties. This opens the door to both glass and carbon fibre materials.

Filament winding is ideally suited to this application, a technology used in the military/commercial sector for the fabrication of rocket launch tubes, rocket motors, chemical pipelines and a variety of pressure vessels, though a new departure for the marine industry. A winding machine is used to place a continuous unidirectional fibre tape onto a mandrel under precise geometric control. Prior to placement on the mandrel, the fibre tape may pass through a resin impregnation bath which is mounted on the winding machine (wet winding) or, alternately, the tape is impregnated in a separate operation prior to the winding process (pre-preg winding). Resin cure is normally effected by post curing the mandrel plus windings in an oven. Cold cure systems are sometimes used but these are in the minority because they cannot be pre-impregnated (a lack of shelf life) and they have a pot life which is rather short, placing severe restrictions on the maximum allowable winding time (hence size of component). Once curing is complete, the mandrel must be removed. There are a number of schemes for this, including soluble mandrels, collapsible mandrels and using a thin former as a sacrificial mandrel which is retained as part of the final structure.

There has been considerable research, both in the West and in the Former Soviet Union, into the feasibility of filament winding a submarine pressure hull using glass or carbon reinforcement. Among the topics investigated are:

Development of a reliable analytical method to predict the buckling/crushing performance of FRP hulls.

Given that buckling theories for simple metallic (i.e. isotropic) cylinders are somewhat inexact, the status of buckling theories for fibre reinforced (i.e. anisotropy) cylinders are even less mature. Studies have been conducted by a number of organisations, including DARPA and ONR in the USA, IFREMER in France, DERA in the UK and labs in the FSU. Though useful experimental data and a better understanding has been gained, the ability to predict with accuracy the limit strength of a filament cylinder in the general case (ie as a function of wall thickness, fibre lay-up and material type), is still beyond current capabilities.

What has emerged is the ability to predict the response of a strictly limited range of cylinders, given some test results on "representative" small scale versions.

Development of optimal pressure hull geometry's.

Putting material type and lay-up geometry to one side for the moment, there are many possible permutations of hull configuration ranging from a thick-walled monocoque to a thin walled, closely spaced, integral rib stiffened arrangement. The principal research work in this area has been conducted in the FSU and in the USA. Design rules have been derived empirically, though it is not known how widely applicable these are.

Optimising the fibre lay-up configuration.

Having previously established that the principal hull loading is a -2(hoop):-1(axial) stress ratio, there are a number of possible winding configurations, ranging from 2 hoop layers /1 axial layer (referred to as a 0(2)/90(1) to mirror the biaxial load arrangement) through a +-55 degree angle ply (to coincide with the biaxial load vector) to a compound arrangement of two or more angle ply configurations. This has been the topic of research in the USA (Cardaroc and Oak Ridge), in the UK (DERA, UMIST, Imperial College), in France (DFN) and in the FSU.

Developing the fabrication route.

The filament winding process can accommodate components of the order 1 metre diameter x 10 metres long x 15 mm wall thickness in GRP on a fairly routine basis. Somewhat thinner (5 mm) components in CFRP are not uncommon. Certain small submersibles fit into this envelope and indeed a limited number of research craft have been successfully designed and built in this way. However the majority of submarine hulls are far bigger than this, perhaps 10 metres diameter, 50 metres in length and requiring a wall thickness in FRP of the order 200 mm.

This is clearly beyond current filament winding practise and has in turn led to a number of issues:

- Building the hull in modules, which can be joined together.
- Co-cured integral rib/hull fabrication versus separately cured then assembled rib/hull fabrication.
- How to cure a thick section composite and avoid damage.
- How to design intrusions into the hull (entry and exit features) and avoid stress concentrations.
- Making a robust FRP hull (i.e. which can survive handling and impact damage)

Seawater System Materials

A submarine platform uses seawater within a number of different systems. The primary use is for cooling the main condensers and the combined heat exchangers of the fresh water cooling systems. Simplistically these systems comprise hull valves, pipe work, valves, pumps, together with the condensers and heat exchangers.

Nickel aluminium bronze castings were selected as the material of choice for the seawater system of nuclear submarines in the 1960,s. The material exhibited a good combination of strength and toughness and shock loading resistance and good general corrosion performance. However after a number of years in service components cast in this alloy were found to be susceptible to severe selective phase corrosion attack. The corrosion was particularly severe in crevices and in weld heat affected zones, especially when associated with low flow conditions or galvanic coupling. Selective phase corrosion rates of the lamella kappa phase as high as 1.1 mm/year were measured. Although there was an extensive programme to look at compositional modifications and heat treatments to try and reduce the corrosion susceptibility these met with only limited success. In part the problem lay with the observed incubation period for the corrosion to commence, the kappa phase appearing to be initially cathodic to the surrounding alpha., and hence the difficulty in determining as to whether any proposed treatment was having a beneficial effect. Although the composition of the alloy is now tightly controlled and welding not permitted on or close to the seawater wetted face corrosion damage of NAB components is the life limiting criteria of the systems of which they are part. The systems need a management system to ensure safe life, with revalidation and replacement of selected safety critical castings at refit intervals. The major contributions to through life costs of these seawater systems are associated with these revalidation costs. At present the candidate replacement for NAB castings is a high strength cupro nickel chromium alloy, however this alloy itself has had casting and welding problems.

For future platforms alternative materials including super duplex stainless steels, super austenitic stainless steels, Inconel Alloy 625 and titanium alloys are being investigated which would give a fit and forget installation, hence giving significant through life cost reductions.

In addition to a replacement for NAB castings titanium has been considered for use in condenser tubes which would allow a U tube design eliminating the need for a return end header. Such a design gives a significant reduction both in size and weight of the condenser and would give opportunities for increased payload. The conventional condenser tube material, cupro nickel has adequate corrosion resistance for a straight through design although it can suffer from hot spot corrosion and sulphide attack. However, the U tube design using cupro nickel tubes would necessitate a reduction in water velocity to prevent erosion occurring in tubes. Such a reduction in water velocity would then reduce the heat transfer performance of the condenser. Titanium in comparison, has a much improved erosion resistance, in fact the water speed could be as high as 30m/s compared to the limit of 3m/s for cupronickel.

In any application fitness for purpose is of importance and an understanding of the fracture degradation processes is crucial. During the early studies on CP titanium it was shown that continuous crack extension could occur at stress intensities below the maximum load toughness. This cracking mechanism has subsequently been referred to as sustained load cracking. The implications of this failure mechanism on service performance on service performance are presently being studied to elucidate the boundary conditions controlling this mechanism. The rate effects observed of increasing yield stress with increasing strain rate were shown to agree with computed curves modeled using a constitutive equation proposed by Cernocky and Kremple. The yield stress of CP titanium is a linear function of the logarithm of strain rate showing an enhancement with increasing rate from 238 MPa to 488 MPa. Under conditions of fixed loading the yield stress will be lower than that measured from a conventional tensile test undertaken at a strain rate of 10-4/s, however, under dynamic or shock loading the yield stress will be higher.

The influence of rate dependent deformation behaviour needs to be considered when assessing the structural integrity of components manufactured from titanium. Work is underway to study rate effects on J R curves and on a broader front to develop a "local approach" to our understanding of fracture.

The local approach is an attempt to use macroscopic constitutive modeling in the understanding of deformation and fracture.

Vibroacoustic Materials

To date all UK submarines have an extensive covering of purpose designed rubber like tiles to provide the required acoustic signature, radiated and self noise signatures. These tiles are labour intensive and costly to apply. The major thrust of our research is therefor directed to reduced UPC and where possible improved performance.

The way head however, is seen to be intrinsically stealthy, structural composites. These will obviate the need for add on parasitic coatings and would replace the steel presently used for fabrication of submarine free flood structure (Casings, fins, rudders, stabilisers hydroplanes etc.). They will thus provide lower UPC when compared to clad steel structures (~20% reduction), will reduce the weight of say a fin by ~40% and it is anticipated that LCC will also be much reduced. The technology is being developed in the submarine composite rudder technical demonstrator programme. To date a 3 dimensional composite structure has been manufactured which is fabricated in such a way as to allow the required through direction compliance necessary for acoustic performance but at the same time has a bending stiffness equivalent to 12 mm of steel. It has a low acoustic reflectivity, low noise radiation characteristics and high intrinsic damping. Ongoing programmes are aimed at providing both Acoustic and Electromagnetic stealth while a further programme is aimed at additionally providing low magnetic stealth features.

As stated earlier traditionally, passive viscoelastic materials are used to reduce the acoustic signature of submarines. However, these treatments presently suffer from a number of limitations, namely:

- Performance varies with depth (pressure)
- Layers are compressible, leading to boat instability
- Performance varies with temperature
- Low frequency performance is poor unless the materials are thick (impractical)

In response to these limitations the SMC have been developing a "smart" active noise control alternative to passive vibroacoustic materials. The active system consists of a sensing layer, an actuating layer and an electronic controller to couple the two together. The principle is as follows:

1. The acoustic sensor (piezoelectric 0-3 composite material) detects an incoming pressure wave and converts this pressure into an electrical signal.

2. The electrical signal is fed to an electronic controller which provides gain and phase control.

3. The modified electrical signal is then fed to the actuator (typically a 0-3 or 1-3 piezoelectric composite material) which results in a movement of the actuator front face. An active compliant surface is created which, with an appropriate control algorithm can absorb the incident sound.

4. The acoustic pressure that is reflected (and transmitted) is monitored and the active control is modified to optimise performance levels.

The advantages of active noise control for underwater signature reduction include:

- layers are incompressible
- performance is not sensitive to pressure or temperature changes
- low frequency performance is good and can be achieved with a thin layer.
- performance levels can be modified to suit particular operational and environment conditions
- stealth capability can be hidden (downgraded) during routine operations (by switching the active system off)

SMC have successfully demonstrated that this technology is feasible, and are now looking to further refine the structures. The construction of a technology demonstrator is being considered.

It is envisaged that these low frequency active systems would be used to compliment existing passive treatments (which perform better at higher frequencies), concentrating on specific problematic areas.

Transducer Materials Research

The transducer materials research covers all aspects of active and passive materials utilised in Sonar systems. One of our main areas of work is characterisation of active materials for Low Frequency Active Sonar's (LFAS). These materials are used in towed array systems for Anti-Submarine Warfare. Under operation, the ceramic material which produces the acoustic energy is subjected to extremely high stresses and voltages. The materials parameters change under these conditions, and at high drive levels the acoustic output can degrade and become very non-linear. Accurate characterisation can reveal the maximum drive levels for the ceramic before this non linear region is attained and also how the ceramic properties change under these drive levels. From this work, a new ceramic material with a lower loss coefficient has recently been recommended for use in high power LFAS systems. The lower loss means the material can be driven at significantly higher power levels before non linearity occurs, thus increasing search range of the Sonar.

Newer types of active material are being examined for use in LFAS systems. Electrostrictive ceramics are of particular interest. These have a superior strain in comparison to the conventional piezoelectric ceramics, but several problems do exist. Primarily a very strong temperature dependence which means the large strain coefficient can be vastly reduced with a small change in temperature, and also the material is very prone to microcracking. New compositions of electrostrictive materials are being investigated in order to reduce these effects and allow the large strain coefficient to be used in an LFAS system

Also within the group, new types of hydrophone materials for submarine flank array applications are being tested. Composite materials are now available with an order of magnitude sensitivity increase. Two specific composites are under development within the research team. These are 0-3 and 1-3 composites. The first number refers to the dimensional connectivity of a passive filler. Hence 0-3's are particles of ceramic in a polymer material, and 1-3's are aligned rods of ceramic again in a polymer material. These composites have several benefits beside increased sensitivity. They are lighter than conventional hydrophones, have a significantly better acoustic impedance match to water, and can be fabricated into arrays. However they are expensive to make and efforts are being made in order to reduce the cost of manufacture.

Even through these materials are expensive to fabricate, smaller 1-3 composite panels are ideal for use in array systems and an international collaboration involving the UK, US and Canadian defence research organisations has been exploring the use of 1-3 composites for mine hunting systems. A 500 kHz prototype imaging system is currently under production and will be trailed in March of this year. This has the benefits of high resolution and wide receive angle.

ADVANCED MATERIALS FOR SUBMARINE CONSTRUCTION

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DERA

PRESSURE HULL MATERIALS

- DEPENDENT ON PLATFORM ROLE, DESIGN REQUIRES HIGH BUCKLING RESISTANCE OR HIGH CRUSHING RESISTANCE
- KEY MATERIAL PROPERTIES
  - HIGH YOUNGS MODULUS
  - HIGH COMPRESSIVE STRENGTH
- CONTENDER MATERIALS
  - STEEL
  - TITANIUM
  - GRP
  - CRP

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SUBMARINE PRESSURE HULL MATERIALS

- STEEL
  - ADVANTAGES
    - READILY AVAILABLE
    - RELATIVELY CHEAP
    - WELL DEVELOPED RELIABLE FABRICATION PROCESS
    - GOOD FRACTURE TOUGHNESS/SHOCK RESISTANCE
  - DISADVANTAGES
    - FERROMAGNETIC , PRONE TO CORROSION
    - DETECTION ISSUES

DERA

SUBMARINE PRESSURE HULL MATERIALS

- **HSLA STEEL**
  - REDUCED MATERIAL AND FABRICATION COSTS
  - LOWER ALLOY CONTENT
  - NO WELD PRE HEAT
  - SAVINGS of 10% of HULL CONSTRUCTION COSTS
- **TWO GENERIC TYPES BEING STUDIED**
  - Cu HARDENED HSLA100
  - B HARDENED BIS812EMA

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HSLA STEELS

EVALUATION PROGRAMME

- METALLOGRAPHIC EXAMINATION
- TENSILE
  - STAR FRACTURE
- IMPACT
- FRACTURE TOUGHNESS
- EXPLOSION BULGE
- STRESS CORROSION RESISTANCE
- CORROSION FATIGUE

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SUBMARINE PRESSURE HULL MATERIALS

- TITANIUM
  - ADVANTAGES
    - BETTER SPECIFIC STRENGTH THAN STEEL
    - NON FERRO MAGNETIC
    - GOOD CORROSION RESISTANCE
  - DISADVANTAGES
    - COST 20X THAT OF STEEL

SUBMARINE PRESSURE HULL MATERIALS

- GRP
  - ADVANTAGES
    - BETTER SPECIFIC STRENGTH AND STIFFNESS THAN STEEL
    - NON FERROMAGNETIC
    - GOOD CORROSION RESISTANCE
  - DISADVANTAGES
    - REVOLUTIONARY FABRICATION
    - COST 15X THAT OF STEEL

CRP/GRP HULLS

- DEVELOPMENT OF ANALYTICAL METHOD TO PREDICT BUCKLING/CRUSHING
- OPTIMISING FIBRE LAY UP CONFIGURATION
- DEVELOPING FABRICATION ROUTE
  - FILIMENT WINDING 1M DIA, 15MM WALL, 10M LONG
  - BUILDING IN MODULES
  - CO CURED INTEGRAL RIB/HULL?
  - CURING THICK SECTIONS WITHOUT DAMAGE

SEAWATER SYSTEM MATERIALS

- **NAB MATERIAL OF CHOICE IN 1960'S**
  - GOOD STRENGTH, TOUGHNESS AND GENERAL CORROSION RESISTANCE
- **IN 1970'S SELECTIVE PHASE CORROSION OBSERVED**
  - 1.1MM/YEAR IN CREVICES AND HAZ OF WELDS
- **COMPOSITIONAL MODIFICATIONS AND HEAT TREATMENTS ASSESSED**
- **REVALIDATION AND REPLACEMENT AT REFIT ARE MAJOR CONTRIBUTION TO THROUGH LIFE COSTS**

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SUBMARINE SEAWATER MATERIALS

- NAB ALTERNATIVES
  - HS CUPRO NICKEL CHROMIUM ALLOY
    - CASTING PROBLEMS
    - WELDING PROBLEMS
  - SUPER DUPLEX STAINLESS STEELS
  - SUPER AUSTENITIC STAINLESS STEELS
  - INCONEL ALLOY 625
  - TITANIUM ALLOYS

Ti CONDENSER TUBES

- U TUBE DESIGN
  - ELIMINATES NEED FOR RETURN END HEADER
  - REDUCTION IN SIZE AND WEIGHT

- BUT INCREASED EROSION
- CuNi 3m/s EROSION LIMIT
- TI 30m/s EROSION RESISTANCE

SUSTAINED LOAD CRACKING

- CONTINUOUS CRACK EXTENSION BELOW MAXIMUM LOAD TOUGHNESS
- BOUNDARY CONDITIONS CONTROLLING MECHANISM BEING STUDIED
- INCREASING YIELD STRESS WITH INCREASING STRAIN RATE MODELED
  - RATE DEPENDENT DEFORMATION IS CONTROLLED BY DEVIATION FROM AN EQUILIBRIUM STRESS STRAIN CURVE

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SUSTAINED LOAD CRACKING

- FURTHER WORK ON
  - RATE EFFECTS ON J-R CURVES
  - LOCAL APPROACH TO FRACTURE
    - BASED ON UNDERSTANDING OF THE MICROMECHANISMS OF DEFORMATION AND FRACTURE

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VIBROACOUSTIC MATERIALS

- SUBMARINES COVERED BY RUBBER LIKE TILES
  - TO PROVIDE REQUIRED ACOUSTIC SIGNATURE, RADIATED AND SELF NOISE SIGNATURES

- CAST ANECHOIC
  - TO REDUCE LCC AND UPC

INTRINSICALLY STEALTHY STRUCTURAL COMPOSITES

- OBVIATE NEED FOR PARASITIC COATINGS
  - REPLACE STEEL IN FREE FLOOD STRUCTURES
  - CASINGS, FINS,RUDDERS, STABILISERS,HYDROPLANES
  - PROVIDE LOWER UPC 20% c/f CLAD STEEL
  - REDUCE WEIGHT BY 40% c/f CLAD STEEL
  - ANTICIPATED REDUCTION IN LCC

INTRINSICALLY STEALTHY STRUCTURAL COMPOSITES

- 3D COMPOSITE STRUCTURE
  - HAS REQUIRED THROUGH DIRECTION COMPLIANCE NECESSARY FOR ACOUSTIC PERFORMANCE
  - WITH BENDING STIFFNESS EQUIVALENT TO 12mm STEEL
  - HAS LOW ACOUSTIC REFLECTIVITY
  - LOW NOISE RADIATION CHARACTERISTICS
  - HIGH INTRINSIC DAMPING

ACTIVE NOISE CONTROL

- PASSIVE VISCOELASTIC MATERIALS LIMITED BY:-
  - PERFORMANCE VARIES WITH DEPTH
  - LAYERS ARE COMPRESSIBLE, BOAT INSTABILITY
  - PERFORMANCE VARIES WITH TEMPERATURE
  - LOW FREQUENCY RESPONSE POOR UNLESS MATERIALS THICK

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ACTIVE NOISE CONTROL

- ADVANTAGES
  - LAYERS ARE INCOMPRESSIBLE
  - PERFORMANCE IS NOT SENSITIVE TO PRESSURE OR TEMPERATURE
  - LOW FREQUENCY RESPONSE GOOD (20dB FROM 2-6kHZ) DEMONSTRATED
  - STEALTH CAPABILITY CAN BE HIDDEN