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FORGED COPPER-NICKEL-CHROMIUM ALLOY FOR SEAWATER SYSTEM COMPONENTS

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Forged copper-nickel-chromium alloy for seawater system components

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Abstract

The high strength copper nickel chromium alloy, NES824, is a prime choice to replace the current nickel aluminium bronze alloy used in cast seawater system components. Difficulties encountered in casting this alloy has prompted the development of a forging production route for some components. This paper describes the studies undertaken to demonstrate the feasibility of a forging route for this alloy. After initial forging trials to establish forging parameters, two components were fabricated. These components were evaluated for structural integrity. One component was destructively evaluated to determine microstructure and compositional variations; mechanical and corrosion properties; and samples used for welding trials using arc and EB processes. All properties were compared with those typical of the cast version of the alloy. The investigations have demonstrated that the forging of copper nickel chromium components is a viable process. The mechanical properties of the forged material were in all cases at least as high as those of cast material. Tensile properties were significantly better. General corrosion rates of forged and cast material were similar. The forged material was more readily weldable.

Introduction

The nickel aluminium bronze (NAB) castings within the seawater systems of some naval platforms have been found to suffer from selective phase corrosion at both crevices and weld heat affected zones. Such corrosion problems have made it necessary for NAB seawater system castings to be regularly validated to determine their remaining life, resulting in the replacement of a significant number of components.

A number of materials have and are being considered to replace NAB in these seawater systems. One leading contender for these high integrity cast components is an alloy based on IN768, and specified in NES 824 Part 1 [1]. This High Strength Cupronickel alloy (HSCN) is basically a 70/30 cupronickel but contains chromium and silicon to give strengthening by spinodal decomposition. This material is compatible with the cupronickel pipework, is resistant to marine fouling and has mechanical properties broadly similar to NAB

[2]. However, the alloy is prone to linear defects caused by the entrainment of oxide films during casting and due to weld repair restrictions are not always reclaimable.

With NAB not suitable or potentially uneconomic and with NES824 components exhibiting casting defects rendering them unserviceable within the existing specifications, together with potential procurement problems due to foundry closures, an alternative production route was sought. Forging is an alternative production route potentially suitable for the manufacture of valve bodies and other seawater system components. The process can produce components to near finished shape, comparable to the existing cast components, with only finish machining of the flange faces and internal bore necessary. Improved structural integrity is ensured through a more uniform microstructure and the essential absence of orientation effects and compositional variations through the component. This process is widely used for steel components for the offshore industry and in pipelines. Copper alloys are forged to make smaller components in other applications. No work had been conducted on the forging of NES 824 material.

Forging

After initial tests and sub-scale forging trials to determine the characteristics of the material, two forgings were produced from a NES 824 copper nickel chromium as-cast billet. For the purposes of this investigation it was not economic to have dies made for a special naval designed component. Dies for an existing design of valve body which had features similar to current naval components were used. The design had two thick flanges, a tapered body and a central boss.

The fabrication process was conducted in three phases. Initially after a homogenisation and soaking heat treatment, the material from the billet was upset. This was followed by a shaped blocker phase when the larger flange and main body of the component was forged. Forging to the final shape was performed by the piercing of the central bore which forced the remaining material to fill out the full shape and top flange.

The first forging began to show surface cracking after the initial forging stages. The cracked region was removed by machining and processing continued. This component again showed cracks after subsequent forging, particularly in the small flange. These cracking problems were initially assumed to be a result of the material containing the original billet pipe region which could contain a concentration of impurity element from the original casting process. However these cracks are more likely to have been due to too low a forging temperature being used or be associated with the material being in contact with the cold metal dies for too long and the resulting temperature drop in the surface layers of the forging material reducing the metal flow and material ductility. Surface ripples and cracks were to be found where the material was required to flow into abrupt section changes, Figure 1.

The second component was forged with fewer problems leading to a generally acceptable component given the limited process development undertaken. At abrupt section changes the metal surface was still rippled and in some locations cracks had formed. These were found to be shallow and were ground out. Some edge cracks on the small flange were also present, these were machined away to investigate their extent and improve overall appearance, Figure 2.

The forging parameters and processes used in fabricating the two test components were not optimised during this exercise. The problems encountered in surface ripples and cracking would be eliminated with forging parameter and process changes in any final forged components for naval service. The process used proved forging as a possible alternative to produce components in CNC that are currently cast, and was sufficiently developed to produce material in the same metallurgical state that would exist in optimised forged components.

Examination

NDE examination of the forged components by eddy current and ultrasonic techniques found no evidence of internal defects. Metallographic examination of the forging reveals the presence of a relatively fine grained microstructure with mean intercepts varying between 40 and 200 mm depending on the position of the material within the forged component. Previous metallographic examination of cast material, showed that grain size was approximately 2 mm. This would suggest that significant improvements in strength and toughness may result. Grain size was found to vary within the large flange from one position to another. The mean intercept length varied between 130 and 185 mm. This was attributed to local variations in the degree of mechanical work encountered during the forging process. There were no signs of the oxide networks that traditionally cause problems in cast components. Chemical analysis was carried out on each of the two forged components, Table 1. It can be seen that in all cases the composition of the samples were predominantly within the specification.

Mechanical Properties

The tensile properties of the forged material compare favourably with those of the cast material, Figure 3. A 30% improvement in 0.2%PS and a 14% improvement in ductility were found. The tensile properties of the forged alloy therefore far exceed the requirements of the NES824 specification, and offer significant improvements over the cast form of the material.

Higher impact energies than the average value for the cast material were found, Figure 4. The impact energies varied between the different orientations and positions. This was attributed to grain size differences due to different extents of hot working. Specimens taken from the forging body contained the smallest grain size, and exhibited the highest Charpy impact resistance. This inverse correlation between grain size and impact strength is as expected. By controlling the grain size in the material, scope exists for ensuring a significant improvement.

20mm thick compact tension specimens were tested and analysed using multiple specimen and single specimen unloading compliance analyses. Specimens prepared from the forging flange gave consistently higher values of fracture toughness than those prepared from the boss, Figure 5. Both sets of specimens exhibited a significantly higher fracture toughness than those produced from cast material.

Fatigue tests were carried out at a stress ratio of 0.1 at a frequency of 20 Hz. There was no significant difference between orientation and location, nor was there a discernible difference in the fatigue crack propagation rates of the forged and cast materials, all of the data falling predominantly in the same experimental scatter-band, Figure 6.

Low frequency fatigue tests were conducted at a frequency of 0.0083Hz at stress ratios of zero or 0.5 in either laboratory air or natural seawater. The general trend was that fatigue crack growth rates in the forged material were either similar to or marginally slower than cast material when comparative conditions were compared, eg Figures 7&8.

Dynamic tensile tests were conducted using crosshead displacement rates of between 1 mm/s and 3 m/s, Figure 9. The values of proof stress and UTS were similar for forged specimens. The proof stress of the forged material is consistently higher than that of the cast materials, and shows a trend of increasing slightly with increasing strain rate. The UTS of the forged material is higher than that of the cast material. Values of UTS seem to be independent of strain rate.

Corrosion and Erosion Properties

Corrosion tests exposed to fresh, once through seawater flowing at 0.3m/s for nearly one year showed identical general corrosion rates of 0.022mm/year for both forged and cast material. There were similar indications of crevice corrosion on all creviced specimens but of no measurable depth.

In cavitation tunnel tests the average erosion rate of the forged material was 22% less than that of the cast material in the cavitation tunnel tests. In jet cavitation tests a comparison of peak erosion rates showed that the forged material was 9% more erosion resistant than the cast material. Hardness measurements showed that the forged material was approximately 10% harder than the cast and the known correlation between hardness and erosion rate is likely to have accounted for these differences.

Weldability

Hot ductility tests were conducted at elevated temperature between 500-850°C since the cast material has been shown to suffer from problems associated with a ductility trough at temperatures of approximately 700°C. The 0.2% proof stress and UTS progressively decrease with rising test temperature as expected. The specimens from the forged material are also consistently stronger than those from the cast material, Figure 10. Both materials however suffer a marked trough in ductility between 600 and 800°C as shown by the measurements of non-proportional strain to failure. Both forged and cast materials seem to suffer from this type of embrittlement to the same extent.

Welding trials were conducted to compare the weldability of the forged material compared with the cast material. MIG and EB weldments were produced. Metallographic sections of each weldment were prepared and bend specimens were tested in accordance with NES825 [3] and then examined for signs of delamination at the weld-parent metal interface. In all cases except for one, the severe plastic deformation applied to the specimens did not result in any signs of delamination or cracking, Figure 11. Only in one cast material, MIG weld specimens, did any sign of cracking occur.

Discussion

Problems occurred during the forging process with the formation of ripples and cracks on the component surface, especially on the first component. The processing technique and the forging parameters were not optimised in this programme. The forging dies were not specifically made for the CNC material, being originally for a steel component. The problems encountered in the forging of the components used in this investigation are likely to be eliminated by further optimisation. The material and microstructure of the trial components will however be representative of forged copper nickel chromium in any future optimised process.

Grain size was found to have an influence on some of the mechanical properties. Some of the variations in grain size observed can be attributed to the degree of mechanical work encountered during the forging process, together with the different cooling rates of the material within the thick sections of the forged component. No signs of any oxide networks were found in the forged material examined.

During the assessment of mechanical behaviour, all material properties were found to be at least as good as those of the conventionally cast material. Perhaps the most significant advantage of forged material over cast lies in the improvement in tensile properties. A similar improvement is seen in the materials dynamic tensile properties. The fracture toughness of the forged material seems to be sensitive to the local grain size. Fatigue crack growth rates for forged and cast material were found to be comparable for each of the combinations of conditions evaluated. These included high frequency air tests and low frequency tests in laboratory air and natural seawater. The general corrosion behaviour of the two materials was found to be identical. The forged material was found to be slightly more resistant to cavitation erosion. This was associated with the hardness difference.

The hot ductility behaviour of the cast and forged materials were similar, both showing a characteristic ductility trough at around 700°C. The general assumption had been that the smaller grain size of the forged material would increase the amount of available grain boundary for the dispersion of deleterious impurity elements compared with the large grained cast material. However the test results suggest that this effect is not sufficient to cause a change in hot ductility behaviour. In the welding studies conducted in this investigation the forged material appears to be readily weldable, with bend specimens indicating that the welds exhibit very good mechanical performance. Specimens containing both MIG welds and EB welds were crack free after testing.

Conclusions

The forging of Copper Nickel Chromium seawater system type components has been demonstrated as a viable alternative production route, although forging parameters need to be optimised to eliminate problems with surface cracking and to allow more reliable microstructural control. Forged components should be free from deleterious defects. They should have a fine grain size. Their tensile strength should be greater than equivalent cast material. Their fracture toughness, fatigue and dynamic properties should be similar or better than equivalent cast material. Their corrosion behaviour should be similar to cast material. Their weldability should be similar or better than the cast material. It may be possible to optimise the forging parameters and component design to ensure the most favourable microstructural conditions and resulting properties in the final component. Optimisation of process and design variables could ensure a more uniform deformation of the feed stock in the formation of the final component. It will be necessary to ensure that these changes do not adversely effect the material properties and its fitness for purpose.

References

1. NES 824 Part 1, Issue 3, "*Copper nickel chromium sand castings and ingots, Part 1, Production Requirements*", July 1993.
2. Hall B N and Townsend D W. "*Copper nickel chromium casting alloy for Naval applications*", Inter Naval Corrosion Conference, RNEC Manadon, 1988.
3. NES 825 Issue 1, "*Requirements for the Welding of High Strength Chromium Cupronickel Castings*", June 1986.

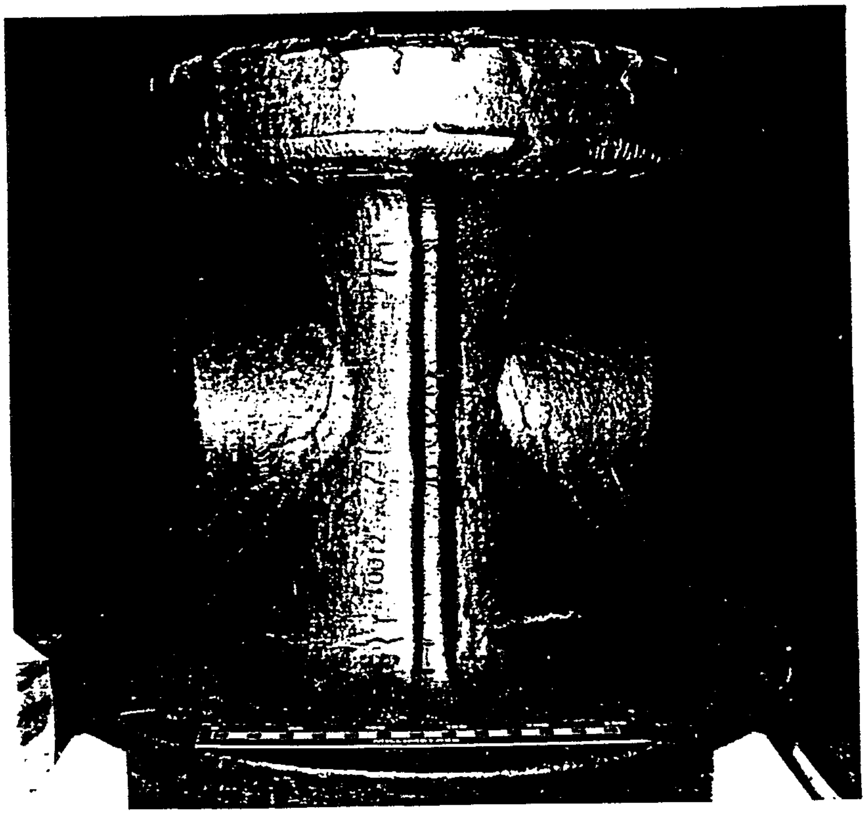

Figure 1. First forged component.

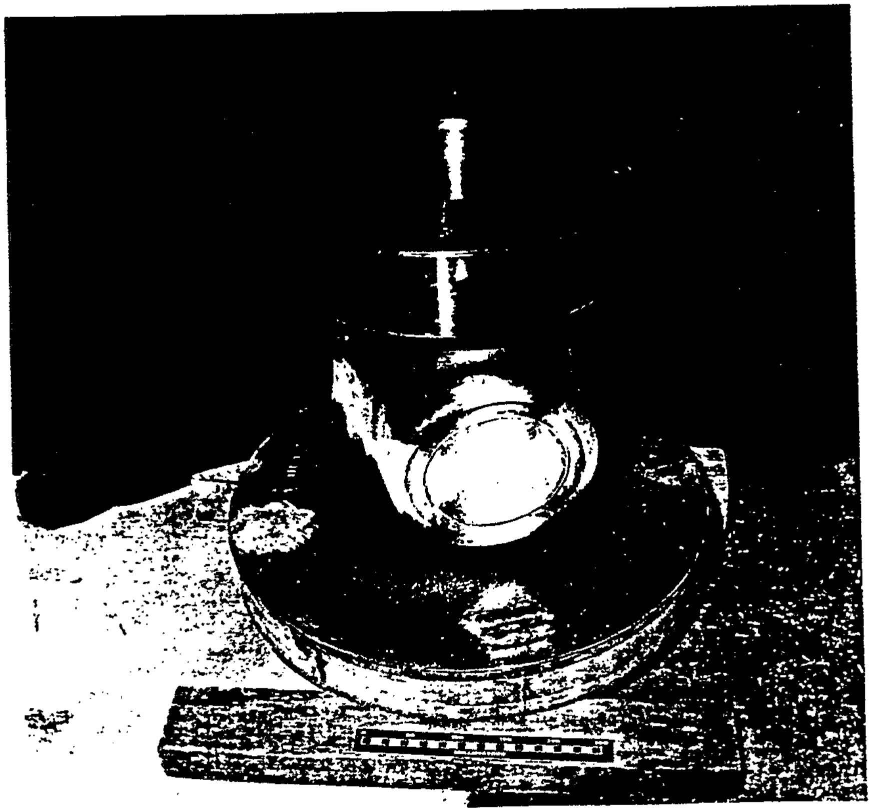

Figure 2. Second forged component.

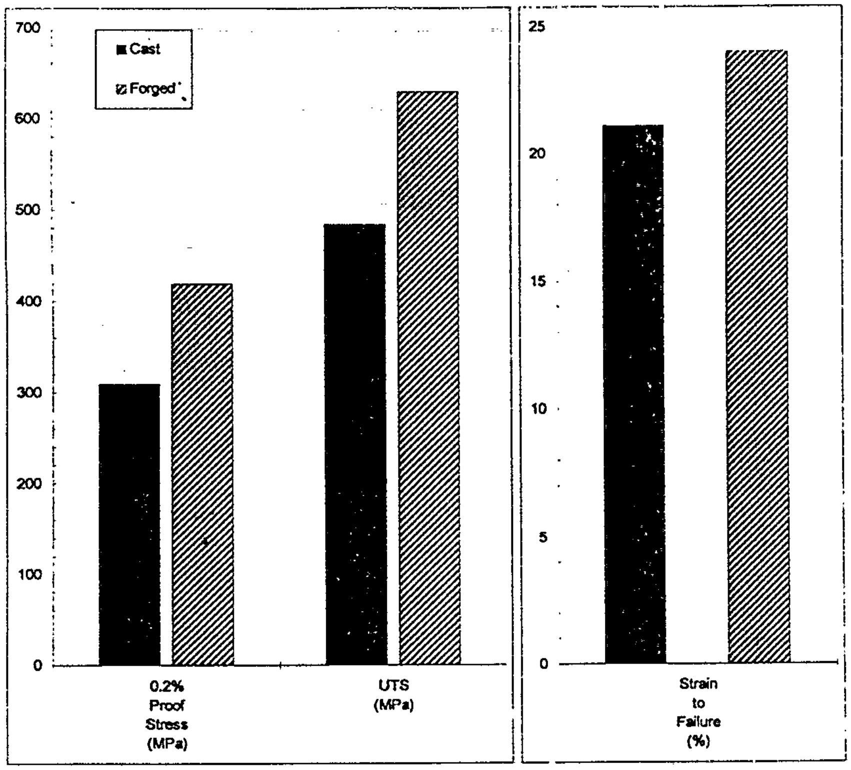

Figure 3. Tensile properties.

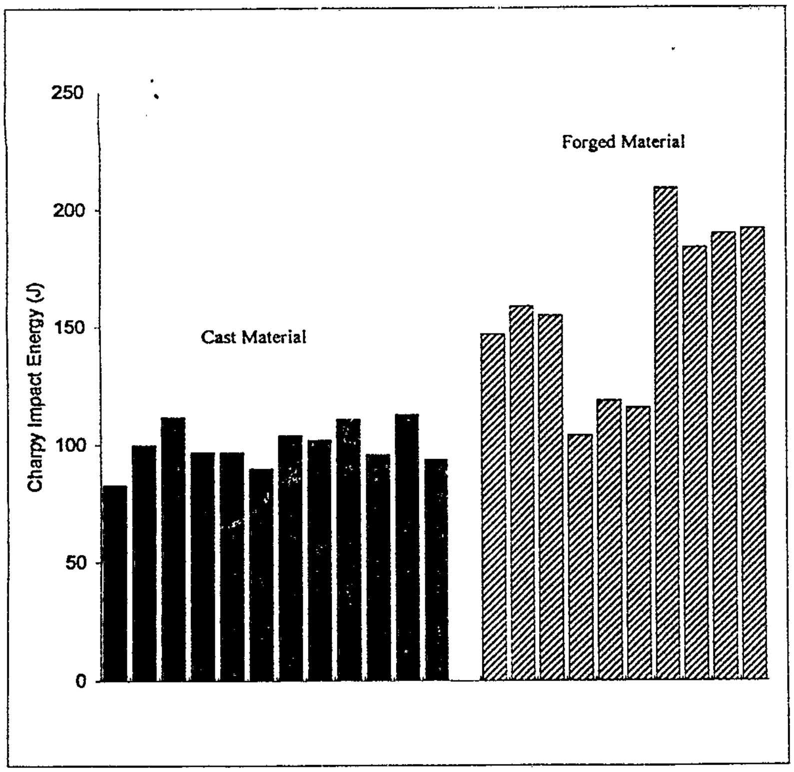

Figure 4. Charpy impact properties.

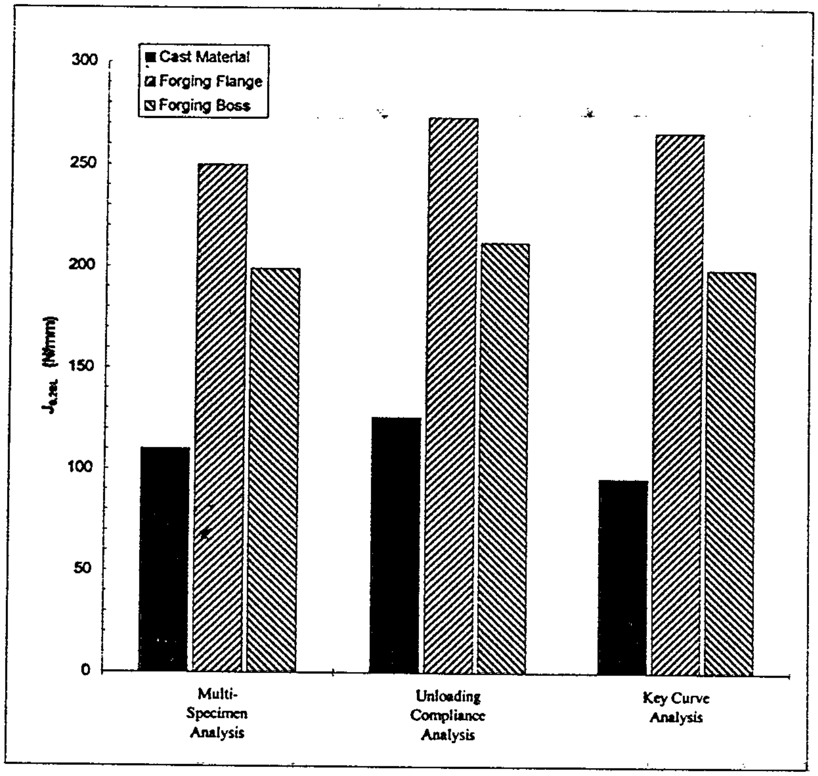

Figure 5. Fracture toughness properties.

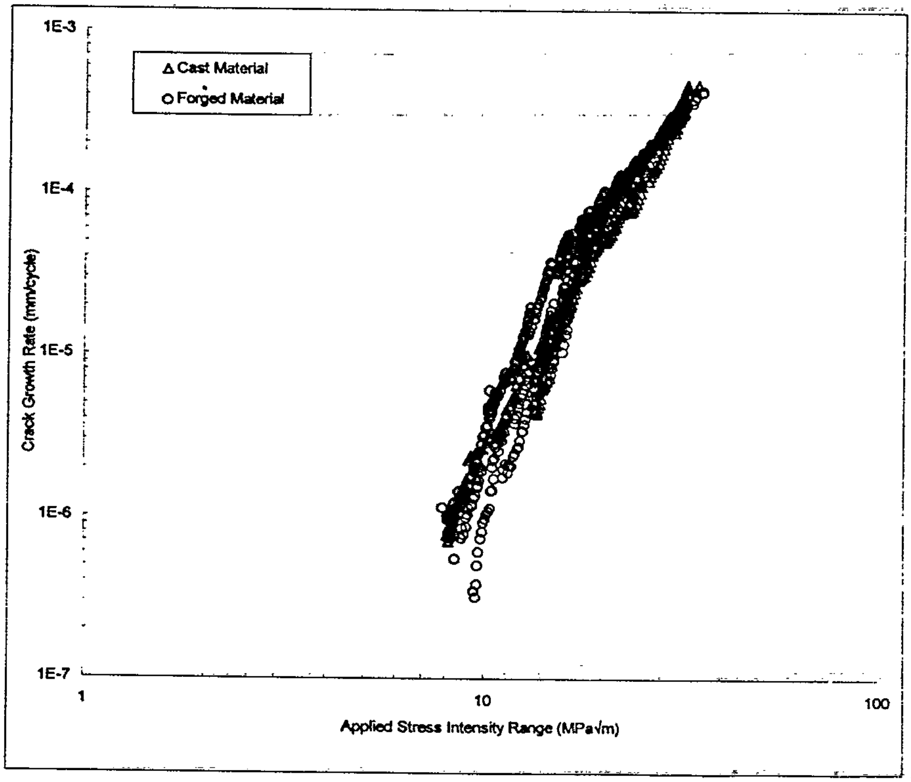

Figure 6. High frequency fatigue (10Hz) in air at R=0.1.

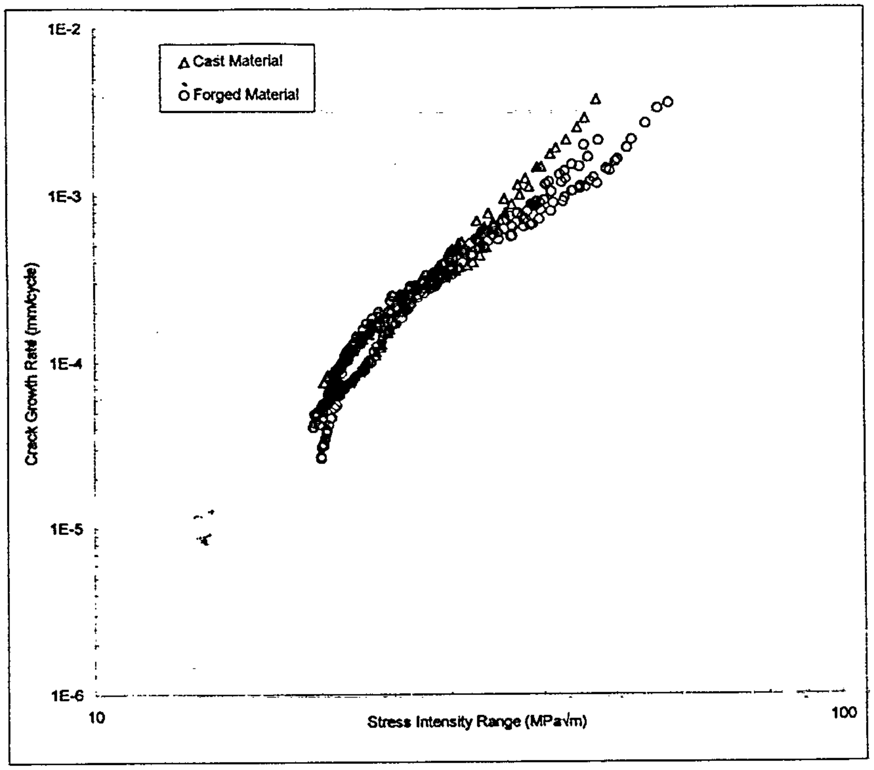

Figure 7. Low frequency fatigue (0.0083Hz) in air at R=0.

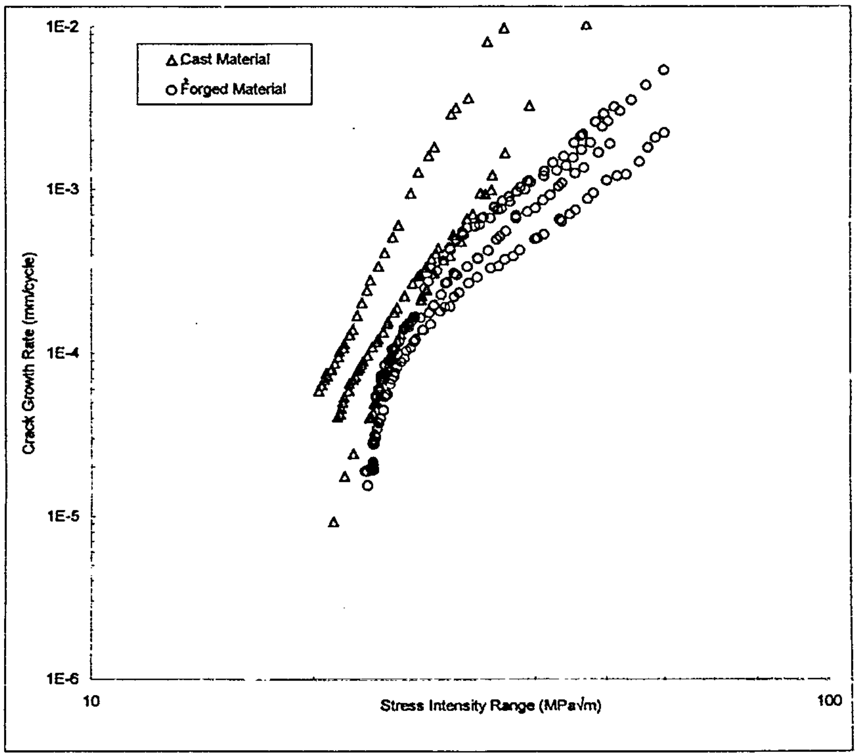

Figure 8. Low frequency corrosion fatigue (0.0083Hz) in seawater at R=0.

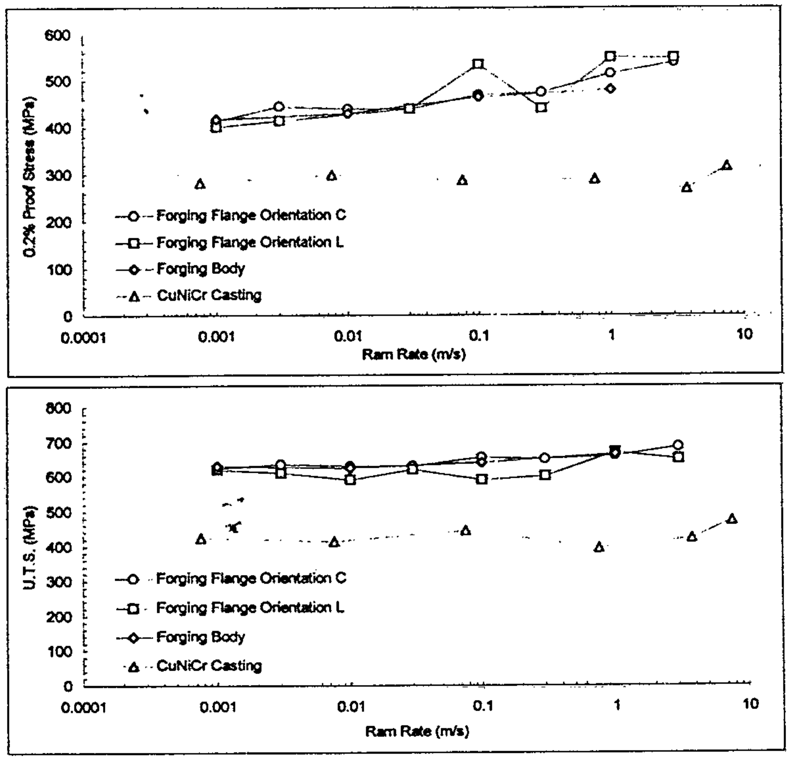

Figure 9. Dynamic tensile properties.

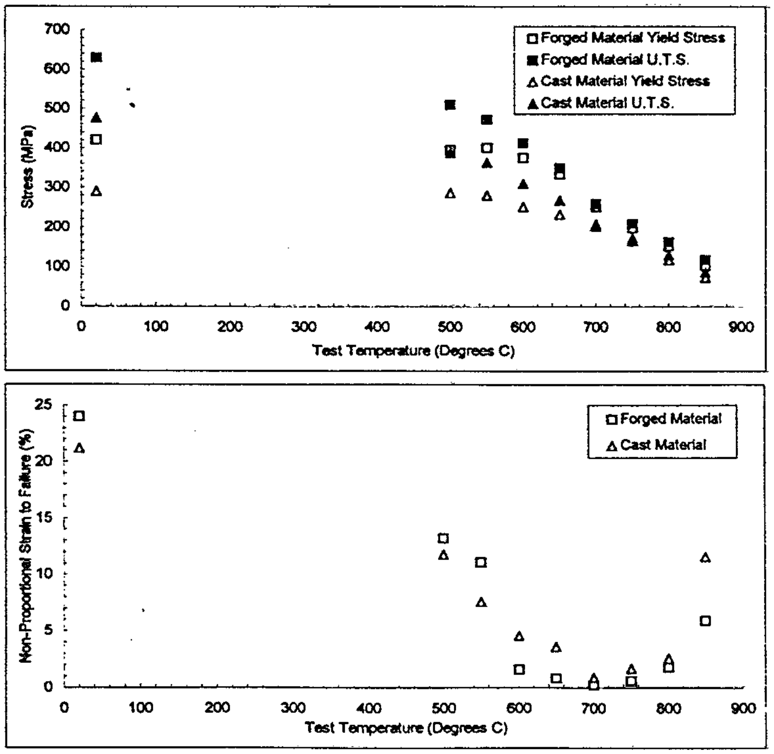

Figure 10. Hot ductility properties.

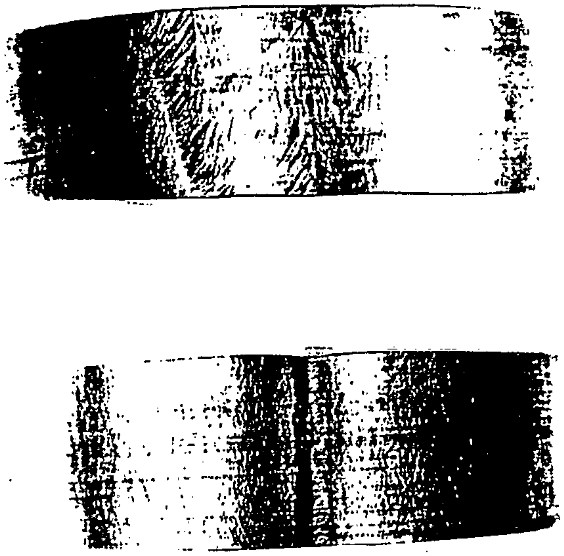

Figure 11. Weld bend tests (a) MIG weld and (b) EB weld.

	TYPICAL CAST	FORGED	NES824[1]
Copper	65.53	66.08 - 67.66	remainder
Nickel	30.75	27.97 - 29.77	29.00 - 32.00
Chromium	1.84	1.66 - 1.81	1.6 - 2.0
Iron	0.59	0.88 - 0.92	0.5 - 1.0
Manganese	0.71	0.74 - 0.78	0.5 - 1.0
Silicon	0.28	0.32 - 0.35	0.2 - 0.4
Zirconium	0.054	0.045 - 0.052	0.05 - 0.15
Titanium	0.099	0.126 - 0.143	0.1 - 0.2
Lead	<0.0005	0.0015 - 0.0022	<0.003
Phosphorus	0.0003	0.0023 - 0.0027	<0.005
Bismuth	<0.0002	<0.0002	<0.001
Sulphur	0.0011	0.0021 - 0.0027	<0.005
Carbon	0.0026	0.0038 - 0.0057	<0.02
Cobalt	<0.005	<0.005	<0.02
Boron	<0.0003	<0.0003	<0.001
Selenium	<0.0002	0.0005 - 0.0006	
Tellurium	<0.0002	<0.0002	
Arsenic	<0.0002	0.0003 - 0.0004	
Zinc	0.0016	0.0068 - 0.0072	

Table 1 - Chemical Analysis of Forged and Cast Components