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USE OF LIGHT WEIGHT MAGNESIUM FOR HIGH STRENGTH HIGH TEMPERATURE CORROSION RESISTANT HELICOPTER APPLICATION

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ABSTRACT

The benefits of magnesium for critical transmission casing components are long established and are based primarily upon light weight.

As improvements are required, however, other materials are considered to replace existing magnesium alloys for new applications, these include aluminium alloys and most recently, advanced polymeric composites.

Aluminium alloys fail to achieve the most important weight advantage of magnesium. Polymeric materials, though competitive in terms of density are unproven, for critical helicopter application, and suffer many suitability limitations which can include properties, producibility and galvanic corrosion.

Advances made in Magnesium development have resulted in improved corrosion protection treatments and, most significantly the advent of a Mg-Y-Nd-Zr alloy WE43. This alloy possesses all of the benefits available from existing magnesium alloys combined with improved mechanical properties which can exceed those of aluminium and are useful to 250°C. In addition, general corrosion resistance of WE43 is improved to the same level as aluminium alloys.

These advances are ensuring magnesium remains the prime choice for lightweight helicopter transmissions.

WE43 alloy will find flight experience with Sikorsky and McDonnell Douglas helicopter companies during 1993.

INTRODUCTION

With a density of only 1.75 kgm^{-3}, magnesium provides components which are only ⅔ the weight of equivalent aluminium components. This significant weight advantage ensures the use of magnesium alloys in aerospace applications and, particularly, for helicopter applications where payload and performance are critically related to weight savings.

In today's environment, designers and manufacturers strive for increased aircraft performance, thus requiring components to become lighter, stronger and operate at ever increasing temperatures. An additional requirement is reduced maintenance and associated aircraft down time cost. One of the factors affecting this is the corrosion performance of the materials used.

The purpose of this paper is to consider how these needs may be best achieved.

1. EXISTING MAGNESIUM ALLOYS FOR HELICOPTER APPLICATIONS

Magnesium alloys are presently used on helicopters, predominantly for transmission casings.

The most commonly used magnesium alloys are shown in **Table 1**.

Alloy	Al	Zn	Mn	Zr	Ce	Mg
ZE41*	-	4.2	-	0.6	1.3	rem
AZ91	9	1	0.2	-	-	rem

Table 1. All values weight %

* ZE41 is the ASTM designation for Elektron RZ5 and BSL128 alloy.

AZ91 is a satisfactory general purpose alloy for application to approximately 120°C where moderate properties are required and pressure tightness (porosity) is not critical.

ZE41, unlike AZ91, contains Zirconium which has a potent grain refining effect. Consequences of a fine equiaxe grain structure are improved mechanical properties, which are consistent through thick and thin casting sections, and a lack of outcropping porosity. The addition of Ce-rare earth serves to improve elevated temperature capabilities and castability. As a result, ZE41 finds favour in applications where components need to operate at temperatures up to approximately 150°C, remain pressure tight and provide consistent properties.

Current applications for these alloys includes the Sikorsky CH53 (AZ91), Westland Lynx, main and tail rotor gear boxes, (ZE41) and Super Puma main and tail rotor gear boxes (ZE41).

These and many other similar applications will continue to use these alloys for the life time of the type of aircraft. For some applications, however, improvements are required and for new aircraft to achieve ever increasing overall performance and life cycle cost, improved material performance is required in terms of reduced weight, mechanical properties at ambient and elevated temperatures, and reduced maintenance cost (corrosion).

These factors have encouraged designers to re-examine materials capable of achieving these goals.

2. SOME ALTERNATIVES

Aluminium alloys

Because aluminium based alloys have a high profile and are in widespread use, designers are often comfortable with this choice. Aluminium alloys have better corrosion resistance than magnesium alloys AZ91 and ZE41, also room temperature properties of some alloys are satisfactory, whilst high strength alloys such as A201 have impressive ambient temperature properties.

Aluminium, however, suffers a significant 35% weight disadvantage to Magnesium (density 2.7 vs 1.75 kgm^{-3}). Aluminium alloys containing Lithium have been developed to reduce density. This, however, results in only around 10% reduction in density and these alloys are not available as sand casting alloys. To approach the weight saving available with magnesium, it is therefore necessary to reduce the wall thickness of castings and, in many cases, increase the strength of the material to compensate for the resulting increase in stress. As wall thickness is reduced, however, stiffness is affected, tolerances become more critical and difficulties are encountered in the foundry. This is further aggravated by poor founding characteristics of high strength alloys such as A201 which have a strong tendency to crack and contain porosity.

Polymer Composites

Polymer based fibre reinforced materials have obtained great interest and, particularly in the USA, enjoyed considerable research investment from the D O D. (ref 1)

The advantages of these materials can include good room temperature strengths, avoidance of conventional corrosion (as seen in metals) and achievement of similar or lower* densities than magnesium (dependant upon matrix reinforcement mix).

These advantages are allowing polymer composites to find use in some aerospace applications such as the Harrier GR5 wing flap (ref 2) and have generated interest for possible future helicopter applications, an exceptional evaluation example being the Sikorsky RAH-66.(ref3) For this application, polymer composites under evaluation include advanced high temperature polyetheretherketone (PEEK), higher temperature Bismaleimide (BMI) and toughened epoxy resins, combined with graphite fibres to maximise stiffness.(ref 3,4)

Some of the drawbacks of polymeric composites, particularly for helicopter transmission casings, should be considered. These include:-

- Poor elevated temperature performance from most polymers due to low softening temperatures, when more thermally capable polymers such as imides are used, toughness suffers and processing becomes more difficult. For example, use of Resin Transfer Moulding (RTM), necessary to allow the use of high temperature thermosetting resins and production of highly loaded structures with large variations in wall thickness, is expensive in terms of both tooling and raw materials. Structures tend not to be as tough as comparable magnesium or thermoplastic (lower temperature capability) structures.(ref4)

- Properties including stiffness are strongly affected by reinforcement and orientation. For example, PEEK reinforced with 40% (by weight) chopped high modulus graphite fibre has been recorded to be only 70% (ref4) as stiff as cast magnesium.

- Epoxy polymers are prone to absorption of water and organic oils which can result in degradation of properties.

- Galvanic corrosion can occur when C or graphite reinforcement is used resulting in two forms of degradation (ref 2, 5, 6) Firstly, severe attack of the metallic component in

*** Example, PEEK reinforced with 40% chopped graphite has a density of approximately 1.6 kgm^{-3}**

contact with the composite. Secondly; imide resins are attacked by hydroxyl ions generated at graphite cathodic sites (ref 6), resulting in degredation.

As an example, BMI/C composite in contact with Aluminium, 3% salt water contaminated with jet fuel exposed for 28 days at 80°C has been reported to result in a reduction in tensile strength and Young's modulus (stiffness) of almost 60% and 40% respectively.(ref 2)

- Thermal conductivity is very poor for polymers, some reinforcements can help. However, if sufficient heat cannot be dissipated through the casing material, the requirement for additional oil coolers adds to overall component weight and complexity.

- Poor noise dampening characteristics is a disadvantage in some applications. For example, the US Advanced Rotorcraft transmission (ART) programme requires a 10d-B reduction in transmitted noise level compared with current state of the art transmissions. (ref 7)

- Machining in terms of component rigidity and cutter wear has been recorded as a producibility risk.(ref 4)

- Use of polymeric composites requires not only choice of suitable materials but often requires new manufacturing and design solutions. This required innovation would be expected to be high, in terms of risk and cost, for critical aerospace applications.

Improved Magnesium Alloy - WE43

In response to the requirement for improved corrosion resistance, (hence reduced maintenance cost) and improved material property capabilities, MEL have developed a magnesium alloy based upon the Mg-Y-Nd-Zr alloy system designated Elektron WE43. Alloy composition is shown in **Table 2** below:

	Y	Nd	HRE	Zr
WE43	4	2.25	1	0.6

Table 2 all values weight %

In common with ZE41, this alloy contains Zirconium resulting in all the benefits of pressure tightness and consistent properties through thin and thick sections.

The presence of Yttrium and Nd combined with a solution treatment and artificial ageing heat treatment (T6), results in the following precipitation sequence.(ref 8)

$$\text{SSSS} \longrightarrow \underset{DO_{19}}{\beta''} \longrightarrow \underset{BCO}{\beta'} \longrightarrow \underset{FCC}{\beta}$$

The precipitates produced have a high population density and provide excellent age hardening response. ß' is the precipitate of interest (fig 1) since it provides an optimum balance of

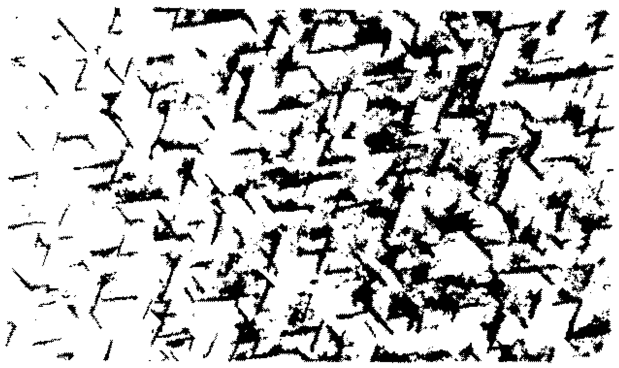


Fig 1 TEM micrography of ß' precipitate distribution. Foil orientation (0001). After Karimzadeh (ref 11).

high strength and ductility. This precipitate is produced by artificial ageing between 200 and 250°C. Once formed, ß' is very stable and ensures excellent mechanical properties which are retained at elevated temperature.

This is illustrated by comparison of WE43 with established magnesium alloys. Figs 2, 3, 4, 5.

It is apparent that WE43 provides consistently improved properties particularly as temperature increases.

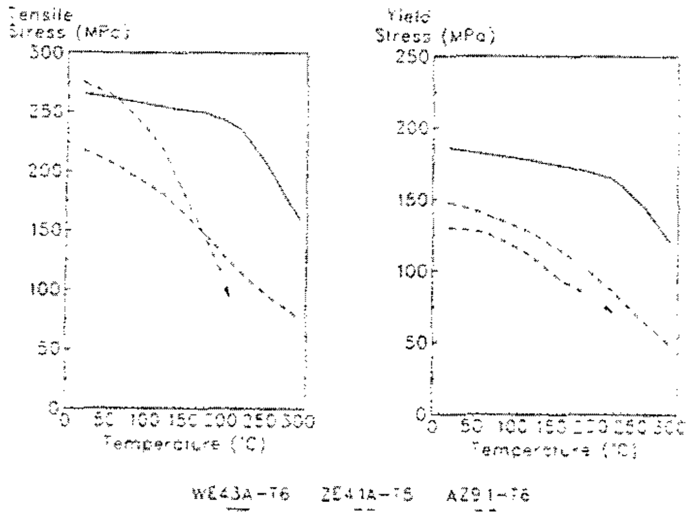


Fig 2 The effect of temperature on the Tensile Properties of Some Magnesium Alloys

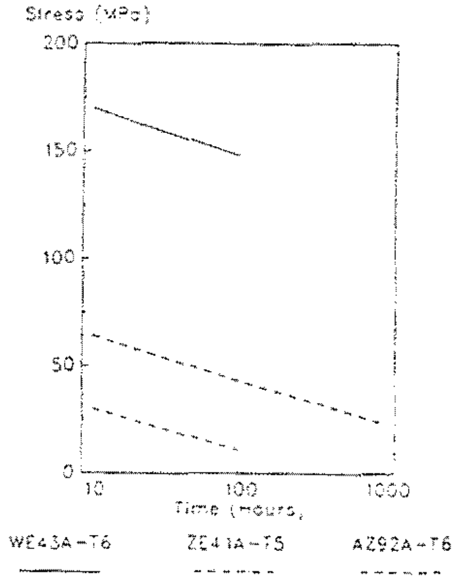


Fig 3 0.1% Creep strain at 200°C for Some Magnesium alloys

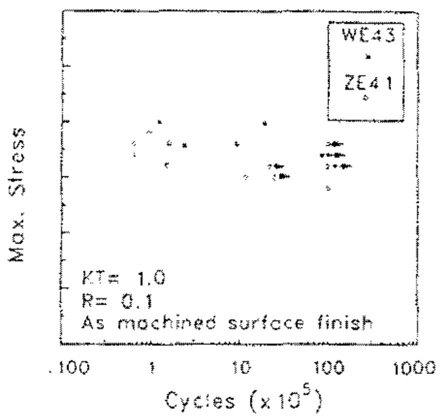


Fig 4 Fatigue at 20°C from a housing casting. Data courtesy of SIKORSKY HELICOPTER

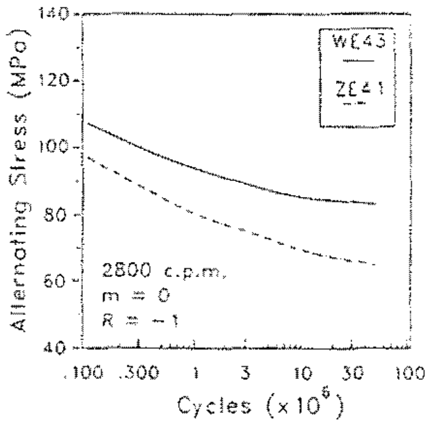


Fig 5 Fatigue at 150°C rotating bend

Notes

Sikorsky comment "fatigue properties of WE43 are similar to ZE41 at room temperature."

Directly comparible date for AZ91 not available however AZ91 is recognised to be lower than WE43 or ZE41(ref 9)

If WE43 is compared to commonly used aerospace aluminium alloys, such as A356 and high temperature A203, it competes directly on a volume basis and can prove even better at elevated temperatures. (Fig 6). Tests by Westland Helicopter (ref 9) demonstrates that whilst aluminium alloy A357 performs satisfactorily, in low cycle fatigue, in more commonly experienced high cycle fatigue, WE43 proves superior. (fig 7)

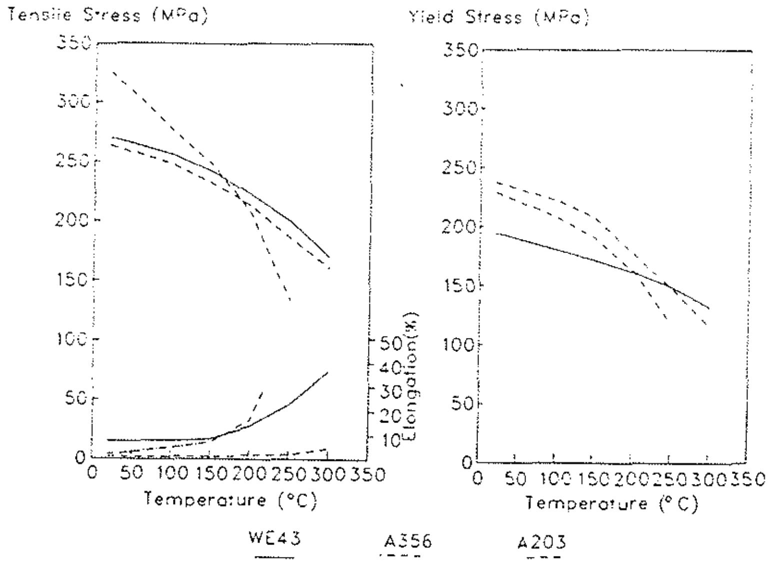


Fig 6 The effect of temperature on the Tensile Properties of WE43-T6 vs Aluminium Casting Alloys A356 and A203

In many age hardenable alloys, attractive mechanical properties of material immediately after heat treatment can be lost as the material rapidly overages if prolonged periods at elevated temperatures are experienced. Long term exposure at elevated temperature is shown for WE43 in fig 8. It will be noted that properties are affected. Many aluminium alloys, however, suffer a drastic reduction in properties in this situation.

A further major attribute of WE43 is excellent inherent corrosion resistance. This is achieved because the alloy is free of contaminants (Zr scavenges detrimental elements such as Fe) and the Y is thought to help passivate the metal surface. Improvements over some currently used alloys is 100 fold making WE43 directly comparable with aluminium based alloys in severe salt water tests. (fig 9). Galvanic corrosion resistance of WE43 is an improvement over ZE41. This advantage, however, is not great.

Corrosion in environments other than salt water can be of

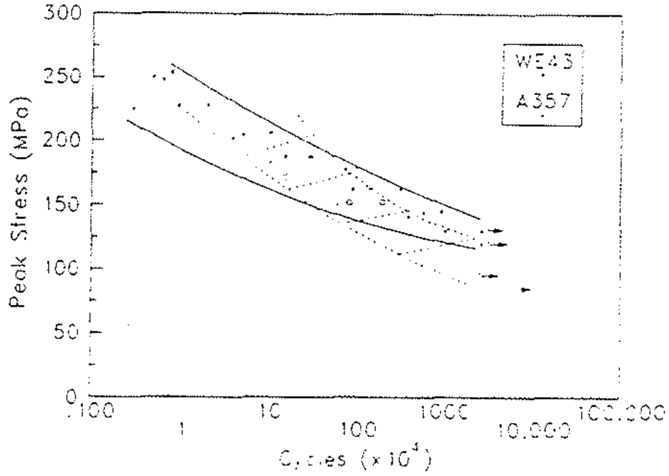


Fig 7 Axial Fatigue Properties of WE43 and Aluminium Alloy A357. DATA courtesy of WESTLAND HELICOPTERS

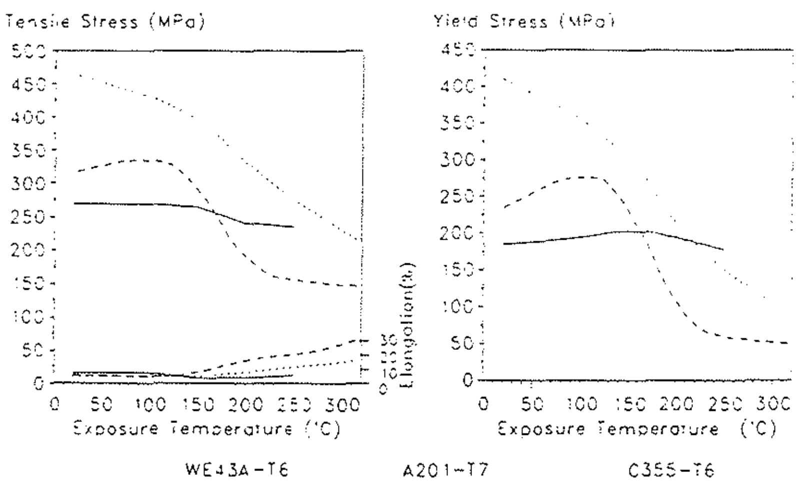


Fig 8 The effect of Exposure after 10,000 hrs. on the Room Temperature Tensile Properties of WE43 vs Aluminium Alloys A201 and C355

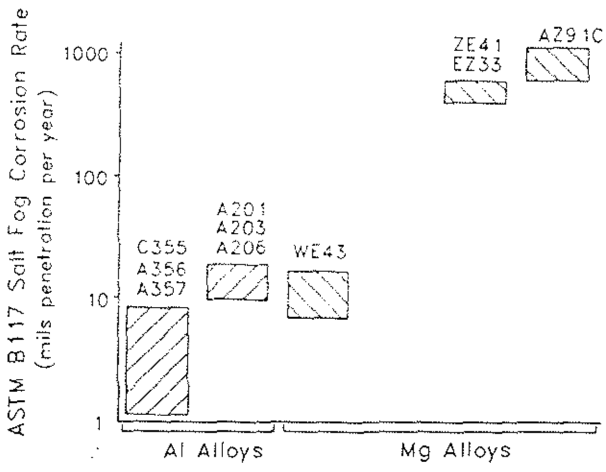


Fig 9 Corrosion Comparison of some Magnesium and Aluminium based Casting Alloys

importance in aerospace applications. Sunstrand Aerospace note that hot acidified oils can attack transmission housings. Sunstrand Aerospace tests, however, indicated WE43 to be much more resistant to corrosion than ZE41. (ref 1)

3. CORROSION PREVENTION

Protection from the environment in aerospace applications is a requirement for polymers and aluminium. Improved magnesium alloy WE43 is no exception. When discussing corrosion protection, both general and galvanic corrosion should be considered.

General corrosion protection of magnesium is presently achieved by one of two basic foundation treatments, prior to painting. Thin (approximately 1μ) chromate conversion coatings for mildly aggressive environments or thicker ($5/40\mu$) hard anodic coatings for aggressive environments such as sea based military applications. Both of these pre treatments contain a degree of porosity. Sealing the pores with resin, known as surface sealing, greatly enhances corrosion protection. This is particularly true for the thicker anodic treatments where surface sealing is essential, if good corrosion resistance is to be achieved.(ref 10)

Techniques to address galvanic corrosion include the use of more galvanically compatible treatments to dissimilar metals (eg Cd plated chromate passivated fasteners) and the use of sealing compounds, applied to fasteners and mating surfaces before and after assembly to avoid moisture ingress. This latter technique is known as wet assembly.

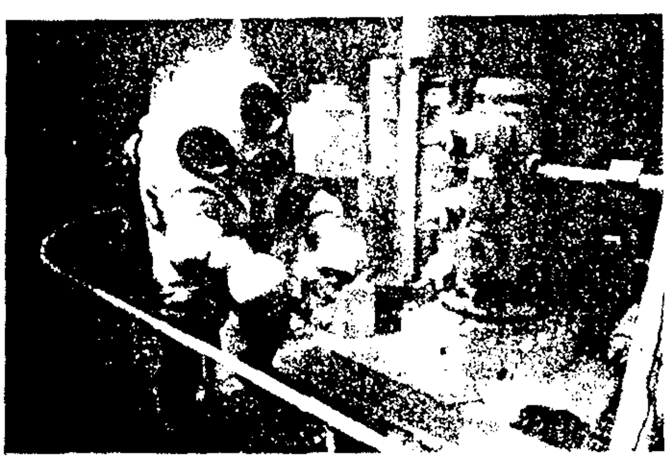


Fig 10 Magnesium (ZE41) bodied deep sea diving suit

These treatments can provide excellent protection when applied correctly. (fig 10). It is, however, accepted that corrosion is seen in some applications. When this does occur it can largely be attributed to:-

- Incorrect choice of protection scheme
- Poor or inadequate application of the protection scheme
- Damage of the protection scheme during assembly/maintenance.
- Poor component design (eg water traps)

Although education offers a general solution, it is recognised that design criteria can restrict surface treatment, for example in high tolerance areas, and inadequate protection can occur due to poor field/maintenance situations.

To assist the magnesium user in these areas, the following developments are in hand.

Improved surface treatments

Developments by coating manufacturers in both Europe and North America have provided several new foundation treatments which offer benefits over presently employed systems. Some of the more promising treatments are summarised in **Table 3** along with currently used HAE and Dow 17 anodic treatments.

Anodic Coating	Bath Constituents	Positive Build-up	Coating porosity (A is least)	Avail-ability	Spec.
HAE	Potassium Hydroxide, aluminium Potassium Fluoride, Sodium Phosphate,Potassium Permanganate	5/40	E	USA/ Europe	MilM 45202
DOW 17	Ammonium hydrogen fluoride, Sodium dichromate, phosphoric acid	8/40	E	USA/ Europe	MilM 45202
Tagnite 8200	Hydroxide, silicate, fluoride	8/25	A	USA	-
Tagnite 8500	Hydroxide, silicate, fluoride, vanadate	8/25	A	USA	-
Advanced Magoxid	Mineral acids, phosphoric/boric acid, Organic substances	20	B	USA/ Europe	-

Table 3

All of the treatments shown offer similar excellent protection from corrosion when tested in the recommended surface sealed and painted condition. Unfortunately, in practice the surface sealing step is sometimes limited or omitted altogether, particularly where fine tolerances are required. When this occurs, DOW17 and HAE perform poorly. Work by Hawkins (ref 11) however, shows Tagnite to provide better protection than HAE or DOW 17 when the surface sealing step is omitted. This is considered to be due to the improved compactness and reduced porosity of Tagnite restricting the progress of moisture through the anodic film.

Surface sealing continues to offer the best protection when combined with anodic films and is recommended. In areas where this is restrictive or not considered feasible (eg high tolerance liner bores, faying surfaces) use of more tolerant Tagnite will provide benefit over currently used Dow 17 or HAE.

Like HAE, both Tagnite and Magoxid do not contain chromates, offering the additional benefit of being environmentally friendly.

Improved galvanic protection

Reducing galvanic corrosion has been examined by several workers, all work is based on the fact that galvanic corrosion will not occur unless all of the following criteria are met.

i) Assembly provides electrical contact
ii) Components of assembly have differing electro potentials
iii) Conductive electrolyte bridges the dissimilar metals.

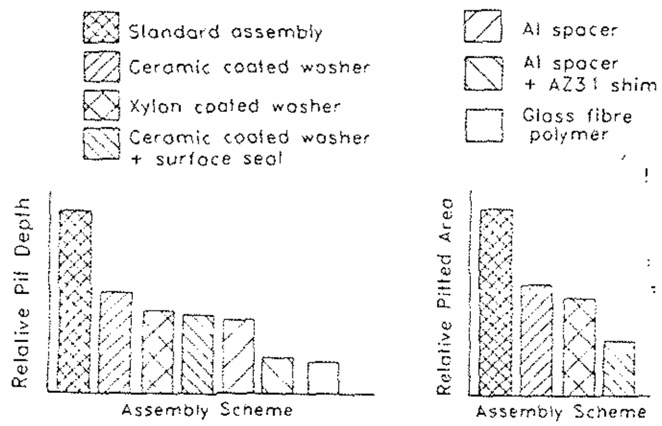


Fig 11 Comparison of galvanic corrosion produced by standard (cadmium plated, chromate passivated) fasteners with other assemblies.

With the intention of minimising either or all of the above factors, MEL (ref 12) have evaluated various fastener coatings and assembly techniques. For each variable tested, a magnesium alloy sample was exposed to standard RAE salt spray test (test solution to DEF 1053 method 36). Each sample consisted of a standard steel fastener which had been cadmium plated and chromate passivated and a similar steel fastener with the test coating or assembly technique.

A summary illustration of the more promising tests are provided in fig 11.

It is encouraging to note at this stage, that all of the techniques shown offer more than 50% reduction in galvanic corrosion on bare magnesium. When conventional assembly techniques, including wet assembly, are also used with surface treated magnesium, the opportunity for galvanic corrosion due to improper treatment or damage is dramatically reduced.

4. IS WE43 BEING USED COMMERCIALLY?

WE43 has been and remains under extensive evaluation by many aerospace end users. Helicopter manufacturers include Bell, Boeing Vertol, Westland Helicopter and Eurocopter. The achievement of the following specifications have supported this activity.

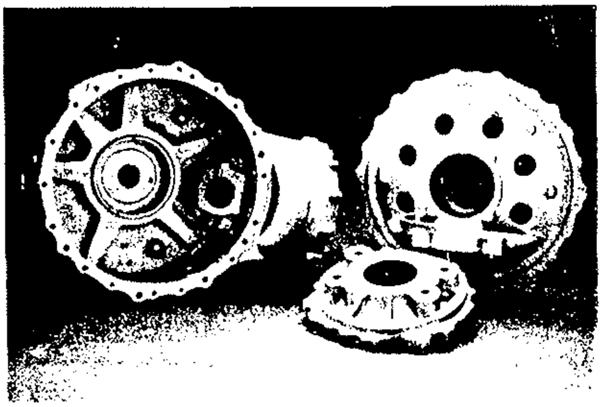
AMS (USA) -	4427
ASTM (USA) -	B80
AECMA (Europe) -	MG-C96002

End users who have satisfied themselves with material characteristics of WE43 and will evaluate WE43 in flight trials during 1993 include:-

McDonnell Douglas

For the main gear box casing of the uprated MD500 helicopter (MD500D) see fig (12,13). Reasons for choosing WE43 are two fold:

- to increase the corrosion performance of the transmission to help improve life cycle from 1500 hours to 5000 hours.
- to allow increased engine output.



Figs 12/13 WE43 MD500 Main transmission housing application

Sikorsky

For main gear box input module component (see fig 14) to provide improved corrosion resistance.

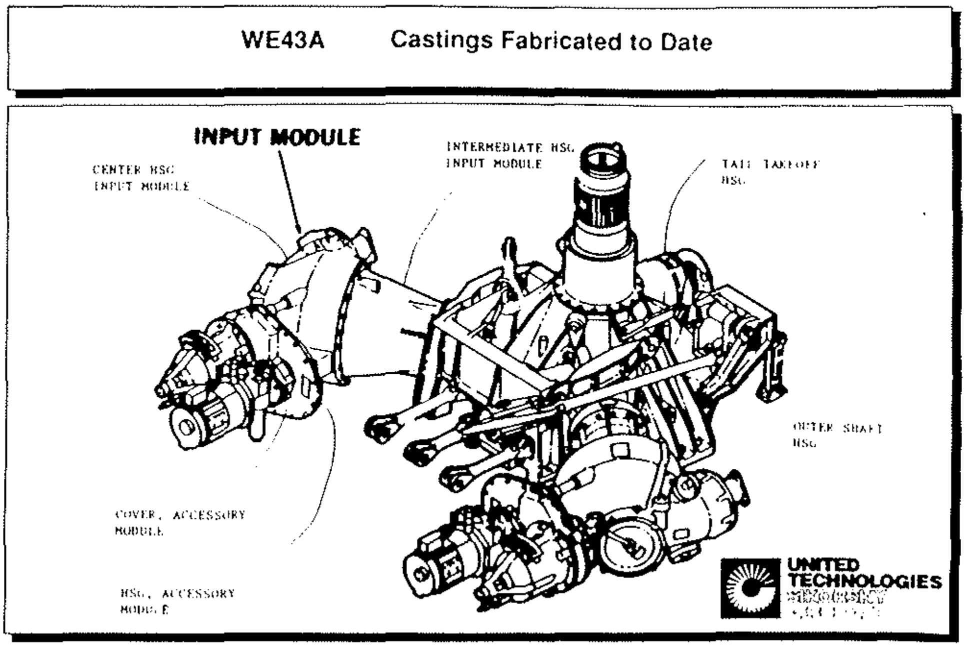


Fig 14 Courtesy SIKORSKY HELICOPTER

For both of these applications, Tagnite surface treatment has also been chosen for flight evaluation.

5. CONCLUSIONS

Many materials are available and have suitability for use on aircraft. Of those considered in this paper all have, or will find, some application because of their various attributes.

The major benefit of magnesium is light weight supported by a proven service history. Because of these reasons, currently used magnesium alloys will continue to be successfully employed. The advent of magnesium alloy WE43 with improved mechanical properties and greatly improved corrosion resistance, will ensure that magnesium remains the prime choice for critical applications, such as helicopter transmission casings, for both immediate and future more challenging designs.

Acknowledgements

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