Title: AERODYNAMIC ARTICLE WITH PROTECTIVE COATING AND METHOD OF BONDING METAL TO POLYURETHANE

Abstract: To protect an article with an aerodynamic surface, such as an aeroengine propeller or helicopter rotor, from erosive damage caused by flying particulate matter, a thin elastomeric protective covering is provided. This layer covers approximately 15% of a forward face (15), a leading edge (12), and approximately 90% of the rear face (13) of the article. Typically it is made of polyurethane with hardness between 85 Shore A and 80 Shore D. It is applied by centrifugal casting using a silane (e.g. gamma-glycidoxypropyl-trimethoxysilane) as a coupling agent when bonding to a metal surface such as aluminium.
AERODYNAMIC ARTICLE WITH PROTECTIVE COATING
AND METHOD OF BONDING METAL TO POLYURETHANE

FIELD OF THE INVENTION

The present invention is particularly concerned
with blades used as rotor blades in helicopters and
propeller blades for aeroplanes.

The invention also relates to other articles used
in aerodynamic applications and has further application in
fluid mechanics.

For convenience the preferred embodiment of the
invention will be described having regard to rotor or
propeller blades, but the invention is not restricted to
these applications.

BACKGROUND OF THE INVENTION

For aeroplanes having propeller blades, the
leading edges of the propeller blades can suffer
significant erosion over a short period of time. This
erosion is exacerbated when the aeroplane uses unsealed
airstrips for landing and take off. The main cause or
erosion of propeller blades is the airborne dust and
gravel which tends to strike the leading edges and rear
faces of the propeller blades. This problem can lead to a
drastic reduction in the life span of propeller blades and
therefore increases the running costs of aeroplanes which
have propeller blades.

When a propeller blade is damaged it normally has
to be completely replaced at considerable cost. The
present invention is aimed at providing a method of
protecting rotor and propeller blades and the like as well
as repairing such articles when damaged.

SUMMARY OF THE INVENTION

According to the present invention there is
provided an article having an aerodynamic surface with a
portion having a protective covering thereon which is
adapted to provide resistance to wear, the portion being
that part of the aerodynamic surface which is prone to
erosion from particulate matter when in use, wherein the
protective covering comprises an elastomer such as a
polymeric substance which is bonded to the portion.

According to another aspect of the present invention there is provided a blade or wing having a portion with a protective covering thereon, the portion including a minor forward face portion, an end edge portion and a major rearward face portion.

Preferably the covering comprises a layer bonded to the portion.

It is generally expected that the blade or aerodynamic surface is metal or a metal composite.

Preferably the minor forward face portion extends from the outermost 15% of the length of the forward face edge of the blade.

The end edge portion may extend from the forward face to the rearward face portion.

The major rearward face portion preferably extends along at least 99.5% of the length of the rearward edge of the blade.

A protective covering preferably extends from the top face of the blade to the bottom face of the blade.

The protective covering may be in the form of a coating.

Preferably the protective covering comprises a polymeric or plastics material.

The protective covering may be rubber 90 duro polyurethane.

The end edge portion preferably comprises approximately 6% of the major length of the propeller as measured from the outermost tip inwardly.

The end edge portion may taper towards the front and rearward face portions.

Preferably the end edge portion comprises the leading edge and has a convex arcuate shape.

The forward portion preferably extends from the forward most edge of the blade.

The top profile preferably shows the portion is thickest at the leading edge and tapers in thickness to
forward and rearward face portions.

According to another aspect of the present invention there is provided a method of covering a portion of a metal surface comprising the steps of treating the surface of the portion with a silane coupling agent to allow bonding of a polyurethane substrate thereto, applying a polyurethane prepolymer to the treated surface of the portion and polymerising the prepolymer, whereby the polyurethane substrate is bonded to the surface of the portion.

The article is preferably a blade of a propeller, rotor or impellor or the like.

The article is preferably placed in a mould and the mould is placed in a centrifuge which is operated to set the polymeric substance in the mould.

It is preferred that the centrifuge is adapted to substantially eliminate bubbles from the cured polymeric substance.

Typically the silane coupling agent is gamma-Glycidoxypropyltrimethoxysilane.

Typically the silane is applied as an aqueous solution, preferably a 2% aqueous solution.

The polyurethane substrate is preferably 90 duro polyurethane.

The words "comprising, having, including" should be interpreted in an inclusive sense, meaning that additional features may also be added.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the present invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a first top view of a propeller blade according to the preferred embodiment of the invention; and

Figure 2 shows a front view of the propeller blade shown in Figure 1.

DETAILED DESCRIPTION OF THE DRAWINGS
A propeller blade 10 according to the preferred embodiment has an elongate arcuate shape with a forward edge 11, outer edge 12 and rearward edge 13.

The blade 10 increases in thickness gradually from the inner end 14 and has a maximum thickness around a location approximately 85% of the length of the blade 10.

It has been found that for an aluminium blade wear to the blade occurs around the 15% mark of the forward face as indicated by item 15 and extends around the outermost edge 12 along all of the rearward edge 13.

It is noted however that close to the trailing edge of the blade (item 14) minimum erosion takes place.

The amount of erosion which occurs is generally at a maximum around the outer edge 12 and tapers off gradually to the forward edge identified by item 15 and to a point approximately 90% of the length of the rear face of the blade 10.

From the 90% mark of the rear face, wear tends to be constant along the whole of the rear face edge.

It is noted that the amount of wear of the outermost edge 12 tends to be around 5mm of erosion.

As shown in Figure 2, to prevent or substantially mitigate the effects of erosion to primarily aluminium blades, an elastomer such as a rubber polymeric coating is applied to the outer edge of the blade 10 as well as the rear face edge 13 and the outermost part of the forward face 15.

At the inner end of the propeller the elastomer coating is of a thickness of between 0 and 0.5mm and at the outer edge of the blade the thickness of the coating is between 1 and 2mm.

The leading edge is contoured so that its maximum thickness at the apex of the propeller is upto 6mm for larger blades and as low as 1mm for smaller blades. It is important that the coating at the leading edge of the propeller is contoured to the shape of the metal part of the propeller so that an aerodynamic foil surface is
provided. Accordingly on either side of the apex of the leading edge the thickness of the coating diminishes. As shown in Figure 1 on the forward face of the propeller the coating extends towards the inner end approximately 0.15 of the overall length of the propeller. Alternatively the coating may be applied all the way back to the trailing edge in order to avoid any abrupt step from the coating to the surface of the propeller. In certain circumstances it may be as much as 0.25 of the length of the propeller.

It is important that the propeller be provided with the coating described above in order to provide maximum wear resistance against erosion.

According to the preferred embodiment this is achieved using a centrifugal application process that also encompasses other application processes followed by a machining process to the preferred thickness.

It is also noted that if a new propeller is made a coating may be applied over the whole propeller as long as the leading edge and/or rearward edge coating characteristics are in accordance with those described above.

As an alternative the blade may be repaired in the following manner.

Firstly any damage is blended out and the blended blade is checked against propeller manufacturer specified minima. Checks are performed for twists, bends and distortions to ascertain whether any dimensional deviation from the manufacturers is within the allowed limited.

The next step is to prepare the bonding surface of the propeller blade and this is followed by providing a silane treatment of the bonding surface.

Next the blade is placed in a mould and the mould is placed in a centrifuge.

It is preferred that the blade is placed with its length parallel to a central longitudinal axis of the centrifuge. Thus when the centrifuge is operated the blade rotates in the same manner as a blade in a paddle
steamer paddle wheel. This substantially eliminates any bubbling occurring in the polyurethane rubber thus providing a smooth finish to the exterior surface of the polyurethane rubber when set.

A polyurethane rubber is then mixed and placed in the mould header and centrifuging is then initiated.
The mould and blade is then removed from the centrifuge and oven curing of the mould blade is initiated followed by stripping of the mould after curing.
The final step is removing the mould flash, final finishing and painting of the blade.
A detailed outline of the above procedures is set out below.

DAMAGE BLEND OUT

Paint strip and clean the blade using standard phenolic paint stripper, Turco 5351. Consult the product data sheet for Turco 5351 to ensure that safety precautions are observed when using this stripper.
Blend out all damage to the blade in accordance with propeller manufacturers data and ensure that the blended blade still meets manufacturer's dimensional requirements. Effect mechanical repairs, for example, straightening as permitted by the manufacturer.
Finish blended surfaces with 320 grit emery paper.

Wash the blade with new MEK (Methyl-Ethyl-Ketone, Aircraft Grade) wipe clean with new industrial tissues. Repeat this procedure using new MEK and changing tissues until tissues come up clean. Ensure that safety precautions are followed when using this compound.

SURFACE PREPARATION

Obtain rectangular test specimen. From this point on the test specimen goes through the same processes at the same time, as the blade.

Scrub the area to which the rubber is to be bonded using Scotchbrite "A" pads and town water. Scrub in one direction along the blade until all scrub lines lie
along the blade and until a water break is achieved, that is, until the complete surface is wetted.

Repeat this process at right angles to the blade until all former scrub lines are removed and the new scrub lines are at right angles to the blade.

Repeat this process now scrubbing along the blade.

Dry the surface with low pressure nitrogen gas, starting from one end, sweeping around the blade and moving from one end of the blade to the other such that the blade is dried with residual moisture being blown off one end.

When completely dry, repeat steps 4.2 through 4.5 using new pads and distilled water. Gloves must be worn throughout this step and after drying, the bond area must not be handled.

SILANE TREATMENT OF BOND SURFACE

Prepare a 2.0% by weight aqueous solution of silane coupling solution (Union Carbide A-187) with distilled water. This solution must be thoroughly mixed making sure that the silane is completely in solution and not coating the surface of the mixing beaker. Mixing must be performed in a clean glass tray. Record shelf life, ambient temperature, humidity and batch number on worksheet.

CAUTION

Silane must be decanted under a nitrogen shield and container must be immediately sealed after decanting. Ensure that when decanting the silane that it does not have a milky appearance, such an appearance will be cause for rejection.

Let the silane solution sit in the mixing tray for 1.0 to 1.5 hours.

Again repeat steps 4.1 through 4.4, this time using the silane solution and a fresh Scotchbrite pad. Hands must be clean gloved. Again scrubbing directions must be along and across the blade with the final scrub at
45° to these two directions and the surface must be fully wetted when complete (i.e. no water break).

Again blow dry with nitrogen. Be sure not to touch the bond surface thus prepared either with the hand or any other object.

Place the blade in a hot air box 70 ± 5°C for 10 minutes.

Discard silane - water mixture after use.

**FIXING THE BLADE TO MOULD AND TO CENTRIFUGE**

Make sure that the mould inner surfaces, riser passages, vents, sprues etc, are clean.

Clamp the blade into the mould and connect the mould to the centrifuge.

Using clean new tubing, connect the mould feeder port to the reservoir. Connect the mould vent port to the port at the top of the reservoir.

Check the centrifuge balance by holding the blade support arm in the horizontal direction. Balance the arm as required by adjusting the balance weights. Give the centrifuge a short run to ensure that balance is reasonable.

**MIXING AND PLACING POLYURETHANE**

Preheat the polyurethane container to 70 ± 3°C so that the polyurethane can be poured from the container.

Polyurethane used is Erapol E90A.

Erapol E90A is a polyurethane having particular characteristics which make it suitable as a coating to a propeller blade. For example it is 90 duro, has good resistance to sunlight and is silane connectable.

Reference is made to a brochure produced by Era Polymers Pty Ltd of 25-27 Green Street, East Botany, New South Wales 2019, Australia. The brochure is entitled "A New Era in Polyurethanes".

It is preferred that the elastomer used in the present invention has a hardness of 85 Shore A to 80 Shore D.

Typically Erapol E90A has an abrasion resistance
of just under 100TS/mg per cycle. An abrasion resistance of greater than 85 is preferred for the elastomer used. These taper abrasion results are based on the use of an H-18 wheel based on 500 cycles.

Reference may be made to the brochure described above for other polymers which have suitable hardness and abrasion characteristics.

It is noted that a selection of a material which has the proper hardness characteristics has a high priority as a product which is too soft will not maintain its aerodynamic properties because it will be too flexible. Accordingly once an elastomer with the correct hardness characteristics is chosen its abrasion characteristics can be obtained to ascertain whether the elastomer is suitable for the present invention.

The elastomer chosen must also be able to adhere to the surface of the propeller and therefore its properties must be matched to a suitable intermediary substance which can bond the elastomer to the surface of a propeller. In the example given in the specification the desired intermediary substance is a silane.

One example of another polyurethane which may be used in the present invention is TU901 which is a product of Conathane.

Continuing with the mixing procedure, the next step is to decant sufficient polyurethane. Decant catalysing agent which is Ethacure 300. Catalysing agent is mixed at 10% by weight with the polyurethane. Thoroughly mix the two together. Record ambient temperature, batch number and shelf time.

CAUTION

Decanting of polyurethane and catalysing agent must be performed under a nitrogen shield.

CENTRIFUGE

As soon as the polymer is mixed, place the mixture into the reservoir of the centrifuge. Then immediately spin the centrifuge for $6 \pm 1$ minutes. The
reason for centrifuging is to eliminate air bubbles and ensure that the mould is completely filled with polymer. Note that polymer must be seen coming up the mould vent tube, indicating that the mould is full and free from entrapped air.

Stop the centrifuge. Disconnect feed and vent fines from the reservoir and remove mould with blade from the centrifuge. At this point the polymer will have started to gel.

CURING THE POLYURETHANE

Place the mould plus blade in a circulating air oven at 65 ± 3°C for 18 ± 1 hours.

After curing, remove the mould assembly from the oven. Strip the mould from the blade. Allow mould plus blade to still air coot.

Clean the mould with ERALEASE release agent.

FINISHING

After cooling, examine the moulded layer for freedom from porosity and shrinkage cracking.

Cut off risers, sprues and vents and the leading edge joint flash, using a plastic sharp edge. Be very careful not to nick the aluminium propeller blade with the knife.

Peel off any edge flash or scale using finger nails or a plastic straight edge. Be sure not to mark the underlying aluminium.

Paint the blade tips as required.

Check the blade mass against the manufacturers specified maximum.

Assemble the propeller in accordance with propeller manufacturers instructions and balance propeller.

If allowable blade mass is not available, check the total mass against the maximum specified on the propeller Type Data Sheet.

TESTING

TEST SPECIMEN

A test specimen shall be manufactured at the same
time and using the same surface preparation, processes and materials that are used for protecting the blades when the blades are being protected. One sample will be made for each polymer mix. The samples are made in accordance with Drawing No.: PROP TEST 01

PEEL TEST

The test specimen shall be subjected to the peel test described in the final procedures protocol, once developed and applicable. Should this test fail, the propeller must be stripped of its protective coating and steps 2.0 to 10.0 repeated.

By providing a blade with a protective coating in the manner described above, it is possible to make a significant reduction in erosion of the erodible edges of the blade. At the same time the protective coating does not adversely affect the performance of the blade which as understood by aerodynamical engineers is subjected to extreme forces as a result of high rotational speeds.

It is preferred that the propeller with the coating applied in the above manner complies with US government code of regulations title 14 Chapter 1, Part 35 (FAR 35).

Preferably the coating is 90 duro, has good resistance to sunlight and utilises silane in the application of the coating to an aluminium propeller or equivalent aerofoil surface.

As discussed previously although there are preferred locations for application of the coating according to one embodiment the whole propeller, rotor or other aerofoil surface is encapsulated in the elastomer coating.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or in any other country.
CLAIMS

1. An article having an aerodynamic surface with a portion having a protective covering thereon which is adapted to provide resistance to wear, the portion including an end edge of the article which is prone to erosion from particulate matter when in use and wherein the protective covering comprises an elastomer substance which is bonded to the portion.

2. The article as claimed in claim 1 wherein the protective covering has a hardness between 85 Shore A and 80 Shore D.

3. The article as claimed in claim 1 or 2, wherein the portion comprises a minor forward face portion, an end edge portion and a major rearward face portion of the article.

4. The article as claimed in claim 3 wherein the minor forward face portion extends from the outermost 15% of the length of the forward face edge of the blade to the outermost edge of the blade.

5. The article as claimed in claim 4 wherein the end edge portion extends from the forward face to the rearward face portion.

6. The article as claimed in claim 5 wherein the major rearward face portion extends along the length of the rearward edge of the article from the trailing edge to the leading edge portion.

7. The article as claimed in claim 6 wherein the end edge portion comprises approximately 6% of the major length of the propeller as measured from the outermost tip inwardly.

8. The article as claimed in claim 7 wherein the end edge portion comprises a leading edge and has a convex arcuate shape.

9. The article as claimed in claim 8 wherein the end edge portion tapers towards the front and rearward face portions.

10. The article as claimed in claim 9 wherein
the elastomer substance comprises a polyurethane bonded with a silane coupling agent to an aluminium surface of the article.

11. The article as claimed in claim 10 wherein the end edge portion has a radial width of 1 to 6mm

12. The article as claimed in claim 11 wherein the portion is part of a propeller.

13. The article as claimed in claim 12 wherein the portion excludes a major part of a top surface of the article.

14. A method of covering a portion of a metal surface comprising the steps of treating the surface of a portion with a silane coupling agent to allow bonding of a polyurethane substrate thereto, applying a polyurethane prepolymer to the treated surface of the portion and polymerising the prepolymer, whereby the polyurethane substrate is bonded to the surface of the portion.

15. The method as claimed in claim 14 where the metal surface comprises an aerodynamic surface.

16. The method as claimed in claim 15 wherein the metal surface is aluminium.

17. The method as claimed in claim 16 wherein the metal surface is the surface of a blade of one of a propeller, rotor, or impeller.

18. The method as claimed in claim 14 including the step of placing an article having the portion in a mould, placing the mould in a centrifuge and operating the centrifuge to set the polymeric substance in the mould.

19. The method as claimed in claim 18 wherein the silane coupling agent is gammaglycidoxypropyl-trimethoxysilane.

20. The method as claimed in claim 19 wherein the silane is applied as a 2% aqueous solution.

21. The method as claimed in claim 20 wherein the polyurethane substance which is bonded to the surface of the portion has a Shore hardness of between 85 Shore A and 80 Shore D.
22. The method as claimed in claim 18 wherein the portion includes from 1 to 6mm of the leading edge of the blade.

23. The method as claimed in claim 22 wherein the portion includes between 0 and 0.5mm at the trailing edge of the blade and 1 and 2mm at the leading edge of the blade, along the rear face of the blade.

24. The method as claimed in claim 23 wherein the portion includes a section of the forward face of the blade extending inwardly from the leading edge approximately 15% of the length of the blade.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

Int. Cl. 7: B64C 11/20, 27/473, C09J 163/00, C09D 175/04

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

Refer to electronic databases consulted below.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

AU: IPC B64C 11/20, 27/473

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Derwent World Patent Index, Esp@cenet and USPTO sites using keywords: PROPELLER, ROTOR, AIRFOIL, EROSION, ABRADING, COVER, PROTECT, SHEATH, etc.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>X</td>
<td>US 5344235 A (WEETMAN et al) 6 September 1994 See whole document, but in particular lines 7-46 of column 6.</td>
<td>1-9</td>
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<tr>
<td>X</td>
<td>DE 3217172 A (KUFFNER) 8 December 1983 See whole document, but in particular line 8 of page 38 to line 3 of page 39.</td>
<td>1-9</td>
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<tr>
<td>X</td>
<td>GB 2047188 A (DUNLOP LIMITED) 26 November 1980 See whole document, but in particular lines 11-17 of page 1.</td>
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[X] Further documents are listed in the continuation of Box C  
[X] See patent family annex

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
  "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

  "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
  "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
  "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  "&" document member of the same patent family

Date of the actual completion of the international search 13 May 2002

Date of mailing of the international search report 21 MAY 2002

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Form PCT/ISA/210 (second sheet) (July 1998)
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<td>X</td>
<td>GB 1349383 A (SOCIETE NATIONALE D'ETUDE, ET DE CONSTRUCTION DE MOTEURS D'AVIATION - SNECMA) 3 April 1974 See whole document, but in particular lines 28-70 of page 2.</td>
<td>1-9</td>
</tr>
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INTERNATIONAL SEARCH REPORT

Box I  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. \[\square\] Claims Nos:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. \[\square\] Claims Nos:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. \[\square\] Claims Nos:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box II  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-13, directed to an article having an aerodynamic surface with an end edge which is covered by an elastomeric substance;
2. Claims 14-24, directed to a method of covering a portion of a metal surface with polyurethane involving the use of a silane as a coupling agent;
   as reasoned on the extra sheet.

1. \[\square\] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
2. \[\square\] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. \[\square\] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. \[\times\] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:1-13

Remark on Protest
\[\square\] The additional search fees were accompanied by the applicant's protest.
\[\square\] No protest accompanied the payment of additional search fees.
Supplemental Box
(To be used when the space in any of Boxes I to VIII is not sufficient)

Continuation of Box No II:

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are different inventions as follows:

1. Claims 1-13, directed to an article having an aerodynamic surface with an end edge which is covered by an elastomeric substance bonded thereto to provide resistance to erosion by particulate matter. It is considered that protecting an aerodynamic surface against erosion by using a coating of an elastomer comprises a first "special technical feature".

2. Claims 14-24, directed to a method of covering a portion of a metal surface with polyurethane involving the use of a silane as a coupling agent for bonding the polyurethane to the metal. It is considered that the use of a silane to bond polyurethane to a metal comprises a second "special technical feature".

Since the abovementioned groups of claims do not share either of the technical features identified, a "technical relationship" between the inventions, as defined in PCT rule 13.2 does not exist. Accordingly the international application does not relate to one invention or to a single inventive concept, a priori.
This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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END OF ANNEX