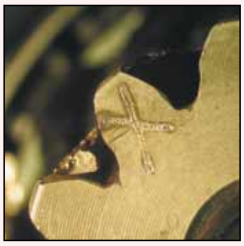
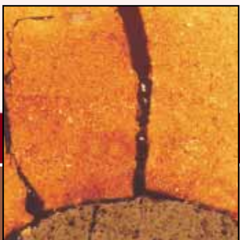




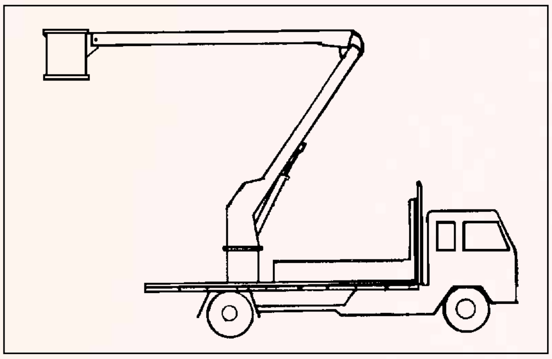
Acoustic Emission Monitoring Of Fibreglass Booms On Elevating Work Platforms (EWP's)

Fibreglass booms are found on most of the EWP's used in, Australia, New Zealand. Fibreglass is used because it is an electrical insulator, it has good strength and is easily made up into a rigid box shape. In the normal course of operations EWPs have been used as rests for tree limbs, to lift power poles or transformers in place, to lift cross arms to extract power poles from the ground and to support cables. None of which the EWP was designed to do. These types of application have the potential for high dynamic loads and have been known to damage FRP booms. Lifting the boom without undoing restraining straps does not do the boom any good either. Unfortunately, some operators have experienced catastrophic boom failures resulting in fatalities.

On January 30, 1979, the safety record of the Philadelphia Electric Company was broken when a double-bucket, articulated EWP unit experienced a sudden catastrophic failure of the FRP section in the upper boom. Prior to this failure, Philadelphia Electric Company had followed an inspection and repair routine developed from manufacturer's manuals and their own experience. An extensive investigation into the failure concluded that the boom had been grossly overloaded for an appreciable period of time at some time during the service life and that at the time of failure it was operating well under its safe working load. The failure was in tension and was sudden and catastrophic. This failure prompted extensive research into the behaviour of, and non-destructive testing (NDT) techniques suitable for, FRP.

In the same year a similar failure occurred in Victoria. As a result of this failure, the USA experience and in-house research many operators adopted regular AE monitoring of loaded booms to ensure structural integrity.

The most recent fatality occurred at Levin, New Zealand in 1986 when an overloaded FRP boom failed at the point where it met the steel section. The report of the DSIR into the boom's failure, recommended annual acoustic emission testing of booms and the Auckland Electric Power Board purchased AE monitoring equipment to test booms in New Zealand. That role has now been taken over by ATTAR (NZ).



All FRP boom failures have been attributed to design deficiencies, poor quality fabrication, in-service abuse, and lack of knowledge of the mechanical properties of FRP and absence of an effective non-destructive testing program.

Non-destructive testing (NDT) of these structures prior to placing them in service and regular periodic in-service inspections can prevent catastrophic failures. Clause 1.5.4.4 (iii) of AS 1418.10 says "The structural integrity of the boom is confirmed throughout its service life by a recognised non-destructive test. The frequency of testing shall be commensurate with the intensity of use and should occur at intervals not exceeding 2 years or after the application of impact or accidental loads. Such requirements shall be detailed in the operator's manual."

However, Australian Standard on in-service use of EWP's (AS 2550.10 - 1994) does not address NDT techniques other than visual examination. You cannot effectively inspect either inside an FRP boom or within the layers of FRP used to make up the boom, visually. AE monitoring of EWP's has been accepted for many years and these tests may be carried out to AS 4748-2001.

Defects In FRP Booms

Defects can be produced in FRP structures at various stages during their manufacture, use and maintenance. Early detection reduces their effect on the service life of the boom. Defects in FRP booms can be created during lay-up and cure, such as voids, thermal stresses, foreign body inclusions and fibre kinks. They can arise

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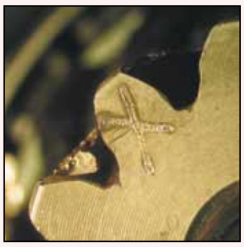
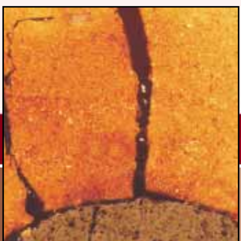

from machining and assembly, such as ply splitting and delamination at holes and free edges, handling damage or damage due to assembly stresses. They can be produced in service by impact, cutting, abrasion, local heating or chemical attack or damage due to overloading as a result of a design fault or inappropriate use; or they can occur during repair, such as porosity in adhesive bond lines.

These defects may occur in isolation but a number of defects could occur together, either of a single type or of several different types. One type of defect might even cause another type to occur such as voids or inclusions initiating intra-ply splitting or delamination. In particular, impacts can produce splitting, multiple delamination and fibre damage, and multiple impact could produce these on adjacent sites.

Mechanical Behaviour Of FRP

As in all fibre composite structures, the mechanical strength of the structure is derived from the fibres, the resin (or plastic) serves only to hold the fibres in place. Consequently, resin damage has no effect on the boom's strength, whereas fibre failure reduces it.

As part of their investigation into the failure of their boom, the Philadelphia Electric Company studied the effect of load and time at load on chopped strand mat laboratory specimens and found when the FRP was loaded to greater than 60% of its ultimate strength, glass fibre failure occurred and the ultimate strength of the FRP was reduced. The amount of strength reduction was related to both the load amplitude and the time over which the load was sustained. Higher loads and longer times resulted in greater strength reduction and earlier failure.

Of course the presence of defects result in localised stress concentrators which mean that lower load/UTS ratios than those observed in the laboratory specimens, so that these can result in serious reductions in the ultimate strength of FRP structures.

Flow-coats

Flow-coats are applied to the FRP structures to provide protection for the FRP from the deleterious effects of the ultra violet light and moisture in the operating environment; they do not provide structural strength. Cracking of the flow-coat on FRP materials is often observed, however, this does not necessarily indicate a reduction in strength. This cracking may be due to a number of factors such as impact, overload, incompatibility of resin systems, incorrect mixing of chemicals and excessively thick flow-coats.

If the cracking is due to impact, characterised by a star-like appearance, the underlying FRP will be damaged. If the cracks are due to overload, ie: nearly straight lines normal to the applied load, then the underlying FRP may be damaged. If the cracking is due to chemically incompatible resins or incorrect mixtures, there may be damage in the underlying composite. If the resins are mechanically incompatible or the flow-coat is too thick the cracks will probably be restricted to the flow-coat.

Non-destructive Testing Of Booms

Dye penetrants are suitable only for detection of surface breaking defects such as cracks or porosity and cannot indicate that the FRP is cracked without removing the flow-coat. They cannot indicate the depth of cracking, the presence of delaminations, or porosity within the FRP.

Ultrasonic inspection may be used to determine FRP thickness and will pick up delaminations but it cannot pick up tight through thickness cracks or be used to examine the steel/FRP interface area where many defects occur.

Acoustic emission (AE) monitoring has been successfully applied to the inspection of FRP structures, particularly EWP booms and storage vessels, around the world. On the basis of these tests, Standard test procedures such as AS 4748 – 2001 have been developed. Its great advantage is that the entire FRP structure is interrogated during the test and only "active" or growing defects are detected.

Loading Of FRP Booms

In the past the recommended procedure, in Australia, for ensuring structural integrity of EWPs has been the application of 1.5 times the SWL in the most critical position AS 4748 calls for loading to the maximum permissible load in the relevant edition of AS1418.10. In New Zealand, AE monitoring is a requirement of the Approved Code of Practice for Power Operated Elevated Work Platforms, set down by the Occupational Health & Safety Authority under the Health and Safety in Employment Act, 1995. The code requires that fibreglass booms on EWP's and buckets must be tested at least every 2 years or annually if they are in arduous service

As 2550 Cranes - Safe Use, Part 10, Elevating Work Platforms:

Published in 1996, this Standard contains sections of concern, particularly in relation to severity of damage and fitness for work.

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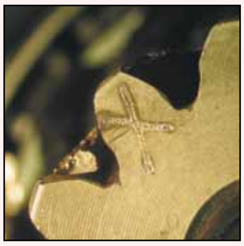
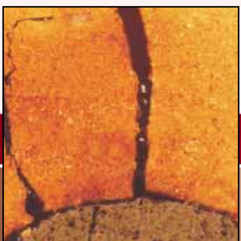

As mentioned earlier, damage due to overload can take the form of cracks in the fibreglass which may be detected on the top or bottom surface of the boom, particularly where the fibreglass insert changes to steel at the lower or elbow end. It can also take other forms, particularly fracture and delamination below the surface when struck by falling objects, anywhere on the boom. This is usually blunt object damage that is often difficult to detect, as indicated in the Standard, and the effect of which is usually greater than just surface crazing. It results in cracking and delamination within the fibreglass and its severity cannot be assessed n the basis of a visual inspection. Its effect may be more than minor and its classification as “minor damage” in the Standard is unwise.

Damage can also occur inside the boom at changes in section or voids within the fibreglass itself. All fibreglass booms contain voids due to the method of manufacture. These defects cannot be detected visually.

Expecting staff untrained in the skills of NDT in relation to FRP to carry responsibility for such assessments is extremely unwise, given that loss of life is a possible outcome of an incorrect decision.

EWP Testing In Australia And New Zealand:

ATTAR has been carrying out AE monitoring of the FRP section of EWP’s since 1986 years and collation of the results of our tests for the period 1/7/1986 to 7/6/05 show that just over 1% of booms were defective, thereby representing a potential threat to the safety of the operator. However, because many of the defects were detected early, most of the unsatisfactory booms were repairable, thus costly replacement was avoided. Booms that have been involved in accidents should be tested prior to repairs, as recent tests conducted on booms involved in accidents were still satisfactory. Some of those booms that were unrepairable were replaced after an insurance claim was supported by acoustic emission test results.

Booms Tested	3097
Unsatisfactory Booms	35
Satisfactory Booms (a)	346
Defect Reported Hydraulic	641
Defect Reported Other Damage	604

The AE test has also indicated areas of minor damage, reported as OTHER DAMAGE in the table, such as gouges, cracks in flow-coat, cracks in levelling rod support bar holes and at inspection holes, as well as looseness between the FRP and steel sections. These defects and any leakage in the hydraulic system are always reported.

AS 4748 suggests the following testing intervals for booms:

Boom	Test Interval
Booms involved in accidents - test to determine feasibility of repairs.	Immediately after accident
Booms giving no AE during test	12 Months
Booms with high damage potential, ie: booms used for tree lopping, replacement of poles, transformers, cross arms or cables and demonstration of abseiling techniques. Test interval should be set by the owner, taking into consideration local work techniques.	12-24 Months
Booms dedicated to light globe replacement	4-5 Years

The test requires the load program shown in Figure 1, using a hydraulic ram and load indicator while monitoring the AE using sensors located on the boom as shown in Figure 2. Customers are required to provide a dead weight in excess of the vehicles rated load, such as a concrete block, transformer, fork lift, etc. Each test takes less than one hour so that vehicles are only off the road for a short time.

Inspection intervals may be set by the owner who should have an understanding of his local work conditions and equipment use. However, vehicles subject to a 10 year inspection should have their booms tested, as an AE test is the only way to guarantee structural integrity.

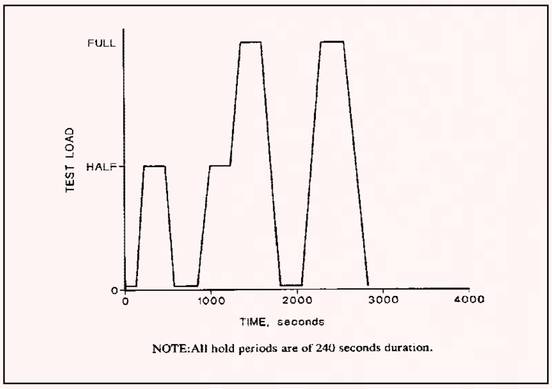

Figure 1. Load application sequence

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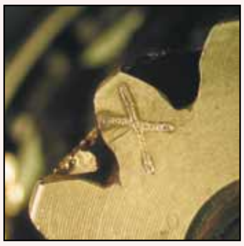
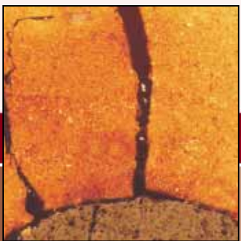

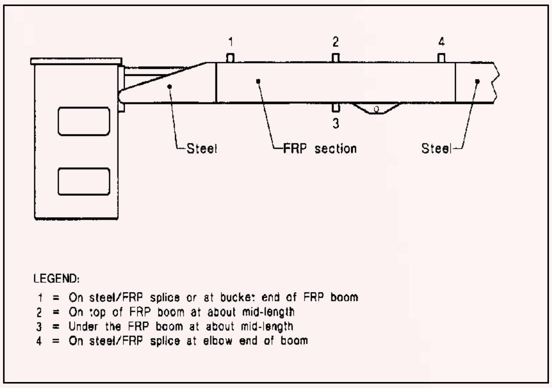

Figure 2. Sensor location

Advantages Of AE Testing:

1. It detects all active defects in the fibreglass boom, as well as movement at the steel/FRP splice and assists in identifying hydraulic system leaks. It does not damage the boom, unless it is already defective.
2. It is quick and thorough, examining the entire boom during the test, detecting defects early in their life enabling repair rather than replacement.
3. It removes the burden of responsibility from managers untrained in the NDT of FRP, provided the test is conducted by a competent operator.

References

- AS 1418.10 – 1994 Cranes (including hoists and winches), Part 10: Elevating work platforms, Standards Australia, Sydney, NSW.
- AS 2550.10 – 1994 Cranes – Safe use, Part 10: Elevating work platforms, Standards Australia, Sydney, NSW.
- AS 4748 – 2001 Acoustic emission testing of fibreglass insulated booms on elevating work platforms, Standards Australia, Sydney, NSW.

A more detailed paper on the subject and further information is available from Gary Martin

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