A CHECKLIST FOR THE DESCRIPTION OF PLANT/VEGETAL/BAST NATURAL FIBRE REINFORCED COMPOSITES

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Keywords: Natural fibre, Plant fibre, Vegetal fibre, Composite

ABSTRACT

Plant/Vegetal/Bast natural fibre reinforced composites are complex systems. This aspect of the materials can result in publications where the description is inadequate to permit full replication of the reported research work. This paper will consider the data which would ideally be reported for a full description of an experimental data set.

1 INTRODUCTION

It is inherent in natural complex systems that comprehensive data is required for a full description. Plant/Vegetal/Bast (referred to as natural below) fibre composites have become a topic of much interest in the context of sustainable materials since the turn of the millennium. Natural fibres [1-3] and their composites, *e.g.* [4-7], have been the subject of numerous review papers. During the conduct of the above reviews, it emerged that many publications which have gone through the refereeing process are lacking in one or more items of critical information. This paper proposes a checklist for data which should be included in any future publications, albeit with the recognition that it may not always be possible to provide every item.

2 CHECKLIST

2.1 Fibre source

For synthetic fibres, the source can usually be identified as a specific factory. For natural materials, it would be useful to know the taxonomic rank (family, genus, species, variety/cultivar, and if available, population/variant and accession). This is especially important where a single word description can be ambiguous, *e.g.* bamboo (*Bambusa*, *Guadua* or regenerated "bamboo viscose"), flax (*Linum* or *Phormium*), jute (*C. capsularis. L.* - white jute or *C. olitorius L.* - Tossa jute) or nettle (*Girardinia* or *Urtica*). Further information should include the field/region/country where the crop was grown, the dates of planting and harvest, the soil condition, quantities of agrochemicals applied and an indication of the (key elements of the) weather through the plant growth.

2.2 Processing

Subsequent to the harvest of the green plant, it will be subjected to processes to extract the bast fibres from the stem (or other fibres from the fruit, leaf, root or seed). If only a specific section of the stem is used as the source of the fibres, then that location should be clearly stated. The processes used for retting (enzyme, dew, stand, water) and subsequent fibre processing (decortication, hackling, scutching, spinning and other textile processes) should be described. For practical purposes the fibres can be classified on the basis of degree of separation. The two levels are elementary/ultimates (typically <50 μm wide) or technical fibres, with the latter, larger entity being assemblies of the smaller units. The ultimate fibre is defined by Denton and Daniels [8] as the "unit cell beyond which subdivision is not possible without loss of a fibre's identity". The method of separation (normally by hand with tweezers) of the elementary fibres from the technical fibre bundle should be stated.

2.3 Fibre (surface) treatment

For a variety of reasons (reduced moisture absorption or improved fibre-matrix bonding) fibres may be subjected to chemical, and/or physical or enzymatic treatments. These include bleaching, enzyme treatments, esterification (commonly acetylation or propionylation), grafting (cyanoethylation or maleation), mercerisation, scouring or surface oxidation by plasma. Any such treatment should be described, or the fibre might be described as "raw state" if none have been used.

2.4 Fibre characterisation

It is essential that there is a clear statement of whether the tests are carried out on elementary/ultimate filaments or technical fibre bundles and on the fibre treatment or surface/interfacial characteristics [9]. Natural fibres have greater inherent variability than synthetic fibres. Further, the cross-sectional area of natural fibres is irregular [10], exhibits greater variation in fibre-to-fibre cross-sectional area [10] and can vary along the length of the fibre [11]. Measurements of these parameters and where possible a calculated fibre area correction factor, FACF, are useful data [12]. When the fibres are assumed to have circular cross-section, there should be a clear statement of this unless there is evidence that the analysis is not affected (*e.g.* only elongation at break is reported).

Cullen et al [13] have presented a novel method for the determination of the density of a natural fibre reinforcement using Archimedes principle in combination with vacuum degassing of the sample.

Further information might include the distribution of fibre lengths, the fibre aspect ratios, and the twist ratio (number of turns/metre). For planar fabrics, the weave style (*e.g.* plain, twill or satin), knitting or stitching pattern, or the process for non-wovens (hydroentangled or needle punched). In all cases, the areal weight in g/m^2 (grams per square metre: gsm) and, for aligned fibres, the yarn count (yarns/metre) in both the warp and weft directions should be given especially for unbalanced (*e.g.* unidirectional) tapes.

Wherever possible, the characterisation should follow international standard procedures (some relevant standards are listed in Table 1), describe the test machine, load cells with calibration data, test speed (e.g. cross head speed or temperature ramp rate) and quote the number of samples tested (only those with valid failure modes, if appropriate) for each test case. Ideally the number of samples chosen should be sufficient to allow the average property with a range or preferably a (Weibull) statistical analysis for each parameter. For the determination of the tensile properties of an elementary fiber, the measurement uncertainties (different stages) were studied by Lefeuvre et al [14]. The influence of the individualization of the fibers on the mechanical behaviour of a composite material (unidirectional ply) is discussed by Coroller et al [15].

For plants, the year-on-year reproducibility is an important consideration. Lefeuvre et al [14, 16] have reported studies of this variation.

Region	Standard	Year	Title
France	XP T25-501-1	2010	Fibres de renfort - Fibres de lin pour composites plastiques - Partie 1 : terminologie et caractérisation des fibres de lin
France	XP T25-501-2	2009	Fibres de renfort - Fibres de lin pour composites plastiques - Partie 2 : détermination des propriétés en traction des fibres élémentaires
France	XP T25-501-3	2010	Fibres de renfort - Fibres de lin pour composites plastiques - Partie 3 : détermination des propriétés en traction des fibres techniques
ISO	ISO 2370	2012	Textiles – Determination of fineness of flax fibres – Permeametric methods
ISO	ISO 8159	2012	Textiles -- Morphology of fibres and yarns -- Vocabulary
ISO	ISO 15100	2010	Plastics – Reinforcement fibres – Chopped strands – Determination of bulk density
UK	BS 7144	2011	Specification for flax and jute fabrics for industrial use

Table 1 Testing standards for natural fibre reinforcements (Year is for the most recent review)

2.5 Preform

Preform information might include the distribution of fibre lengths, the fibre aspect ratios, and the twist ratio (number of turns/metre). For planar fabrics, the weave style (*e.g.* plain, twill or satin), knitting or stitching pattern, or the process for non-wovens (hydroentangled or needle punched). In all cases, the areal weight in g/m^2 (grams per square metre: gsm) and, for aligned fibres, the yarn count (yarns/metre) in both the warp and weft directions should be given especially for unbalanced (*e.g.* unidirectional) tapes.

2.6 Conditioning before composite manufacture

Natural fibres are hygroscopic and thus absorb moisture from the surrounding environment. The extent of moisture absorption will depend on the relative humidity and the time that the fibres are exposed to the environment. It is essential that moisture levels are well controlled before and during manufacture of natural fibre reinforced polymer matrix composites [5] and that the data is presented in any manuscript. Armstrong and Barrett [17] state that ‘Nomex and other aramid honeycomb should be stored in a clean environment at approximately 20°C (68°F) and in a relative humidity not exceeding 65% and preferably lower. It should be dried for 16 h at 40°C (104°F) immediately prior to use. Alternative drying cycles are 1 h at 160°C (320°F) or 3 h at 100°C (212°F)’ and ‘ Dried materials should be used within 1 h of drying, or a further drying process immediately before use will be necessary’. Davis [18] suggests that moisture control can be achieved by storing cores in a dedicated room maintained at 50°C and <10% RH. In the absence of other formal requirements for natural fibres, these conditions should be regarded as a minimum requirement for the fabrication of good natural fibre composites.

2.7 Composite manufacture

There should be a clear statement of the process (wet/prepreg hand lamination, vacuum bagging, resin transfer moulding, resin infusion, compression moulding, *etc*) with the conditions (temperature, pressure, humidity) during manufacture. Resin infusion covers a multitude of options and should be specified using the taxonomy developed by Summerscales and Searle [19]. The mould tool should be fully described (two engineered surface, a floating splash too/caul plate, or a second bagged surface with in-bag consumables listed). The full cure and post-cure schedule (time-temperature-pressure history) should be given. The cooling rate is also important, as it can influence the (residual) stress state, and especially for thermoplastics where it will influence the degree of crystallinity.

2.8 Specimen preparation and testing:

The conditioning and preparation of specimens for tests should be described. Specimens might be moulded to net shape or cut using traditional machining, abrasive water jet, laser, or other means. The special tools and techniques developed for machining aramids [20, 21] may be more relevant than traditional routes for cutting natural fibre composites. The comments in §2.4 Fibre Characterisation apply equally here.

The machining of samples presents new surface which may reveal that porosity (strictly connected channels) and/or voids are present in the composite. Summerscales [22] has reviewed the defects which are likely to arise during the manufacture of composites and those non-destructive testing techniques which could be used to detect their presence. Microscopy and/or image analysis [23, 24] can then be used to gauge their severity and quantify the respective features.

3 CONCLUSIONS

Many publications on natural fibre are lacking important detail. This paper aims to guide authors and referees towards ensuring a manuscript has all essential information. Of course, there are circumstances (e.g. page limits) where inclusion of every item would be inappropriate. Authors are also encouraged to state what is not known, *e.g.* to the best of our knowledge the fibres had not been subjected to any surface treatments. The authors accept that there will be occasions when information cannot be included for commercial reasons.

4 ACKNOWLEDGEMENT

This paper updates a presentation given at the 2nd International Conference on Natural Fibers – From Nature to Market (ICNF2015) held at São Miguel – Azores (Portugal) during 27-29 April 2015.

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