DUST EMISSION AND STRENGTH LOSSES DUE TO HANDLING OF REINFORCEMENT FIBRES

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SUMMARY: Handling, storage conditions and wear of machinery parts are known to have strong influence on the performance of fibres in manufacturing operations. Methods of simulated handling of fibres and sampling of released dust are presented. A simple rig for handelability testing is presented. For dust sampling, a new sampling chamber working with absolute filtered has been constructed. The design includes two concentric chambers with laminar flow of air in the sampling region and a overpressure laminar air flow mantling around the sampling region in order to avoid contamination from the surrounding air. The stress build up is analysed from the bending radius, the drive belt formula and Herz contact stress relations. Silver steel has been used as a kind of standard. Sharp scratches and corrosion however have strong influence on performance of organic high modulus fibres. Damage is discussed from ductility, brittle modes of fracture and behaviour of surface coatings.

KEYWORDS: Fibre handling, strength losses, friction, damage, ductile behaviour, brittle behaviour, dust emission, dust sampling.

INTRODUCTION

Handling, storage conditions, wear and damage of machinery parts are known to have strong influence on the performance of fibres in manufacturing operations. The accumulation of fibre damage and the release and transport of fibrous dust in the handling and processing of fibres are known to be crucial features limiting the use and the utilisation of their inherent properties in applications [1]. In industrial practice however, spin-finishes and sizings are frequently used in order to improve the performance of fibres in the handling operations and end-use. The first direct contact is thus usually not directly to the fibre bulk material, but to some surface coating.

Dust particles are usually classified with respect to their aerosol properties and the subsequent medical risks as:

- Respirable dust, dust reaching the alveol region of the lungs
- Inhalable dust, dust reaching the upper airways
- Non inhalable fragments

Respirable and inhalable dust are potential hazards for lung damage. Depending on the surface chemistry however, non-inhalable fragments can affect the nose region and stiff fragments with sharp tips penetrate human skin and possess thus potential medical risks.

There are also practical and fundamental reasons to distinguish between the dust formed in the processing and the dust existing among the virgin fibres. The dust delivered with the fibres may be more or less mobile. The sizings and spin-finishes, i.e. coupling agents and lubricants can act as bonding agents for the dust. A reasonable classification of the dust related to the fibres and the handling processes is thus [3]:

- Mobile dust, released during processing
- Sessile dust, bonded during processing
- Formed dust, formed by processing

The dominating mechanisms behind sliding friction depend on the speed. In the low speed range, adhesion and debonding dominate together with plastic flow. At high speed with industrial spin finishes on the fibres, the viscosity of the lubricants dominates the behaviour [1]. The analysis of the contact stresses is based on the drive belt formula and the Herz contact stress relations in the form used by Timoshenko and Goodier [6-9]. These equations are used for the analysis of the frictional force results.

The normalised difference of length, i.e. strain difference between the outer tensile loaded side and the inner compression loaded side of a fibre not changing its shape when bent on a cylinder is given by :

$$\Delta\varepsilon = \frac{R_1}{R_1 + R_2} \qquad (1)$$

R_1 fibre radius, R_2 bending radius

The stress and strain of a linear elastic material are related by the Hookes law :

$$\sigma = \varepsilon E \qquad (2)$$

σ stress , ε strain

For an ideal elastic - plastic material, the stress is limited by the onset of yielding :

$$\sigma = \sigma_{pl} \qquad (3)$$

E elastic modulus

σ_{pl} yield stress

The mechanical behaviour and the mechanisms of damage and fracture are related to the microstructure of the fibre. Models for the different modes of deformation and bending behaviour of technical fibres are reviewed in [3]. In bending there is also a tensile force component perpendicular to the fibre axis. There will thus be deformations causing changes in the shape of the fibre. For fibres of yielding types, these changes in shape are depending on time due to transverse creep.

The following analysis is based on the drive-belt formula, with linear elastic properties assumed only for the derivation of the contact stresses. The friction force build up on a positively curved surface is given by the drive belt formula:

$$F_1 = F_0 \exp(\mu\theta) \qquad (4)$$

F_0 preload force

F_1 tensile force due to friction

θ contact angle

Testing the handleability of a fibre or yarn in a full down-up cycle in a tensile testing machine using a set-up described below, the friction force build-up and the coefficient of friction are given from equation (4) combining the motion down and up [3,4] :

$$\ln F_1 - \ln F_2 = 2\mu\theta \qquad (5)$$

F_1, F_2 tensile forces due to friction

F_1, and F_2 are the tensile forces due to friction in downward motion respectively upward motion. With the rig in downward motion, F_1, the friction build up force is added to the pre-load, and the reverse in upward motion.
Using the Herz contact stress relations according to Timoshenko and Goodier, the contact pressure and the shear stress due to friction can be derived for linear elastic fibres [6-9]. The pressure between the fibre and the guide is given by equation (2):

$$\sigma_T = \frac{1}{2}\sqrt{\frac{F_1}{R_1 R_2 (k_1 + k_2)}} \qquad (6)$$

The shear stress is finally given by :

$$\tau_1 = \frac{\mu}{2}\sqrt{\frac{F_1}{R_1 R_2 (k_1 + k_2)}} \qquad (7)$$

$$k_1 = \frac{(1-\nu_1^2)}{\pi E_1} \qquad (8)$$

E_1, E_2 elastic mod

$$k_2 = \frac{(1-\nu_2^2)}{\pi E_2} \qquad (9)$$

ν_1,ν_2 Poissons ratii

EXPERIMENTAL PROCEDURE

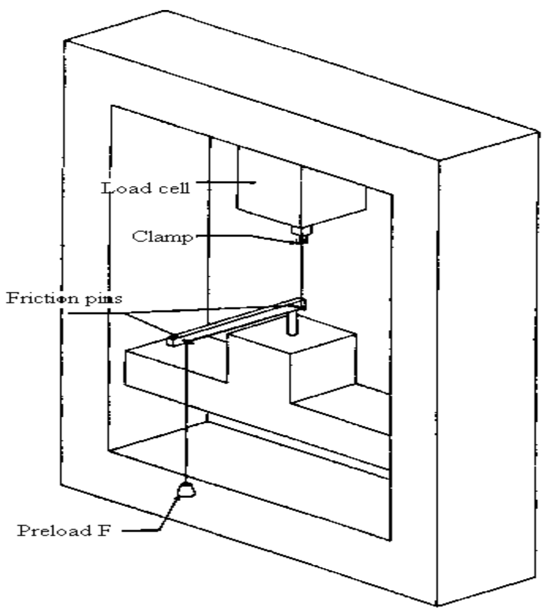


Fig.1. illustrates the principle of the set-up for handleability testing

The handleability testing is performed in a simple rig for studies of frictional stress build-up, damage formation and emission of dust in a standard tensile testing machine [2-5]. The total contact angle θ is 200^{o}. The motion is given by the frictional pins on a fork mounted on the beam of the machine. The method can in principle be regarded as a modification of the ASTM standard method for testing of friction yarn to metal [1].

The merits of this kind of set-up are the possibilities to use an ordinary tensile tester, the well-defined mechanical conditions with the pre-load weight and yarn static and the possibilities to identify the location of the events of damage on the fibres and force displacement recordings during the testing of the specimens for further examination.

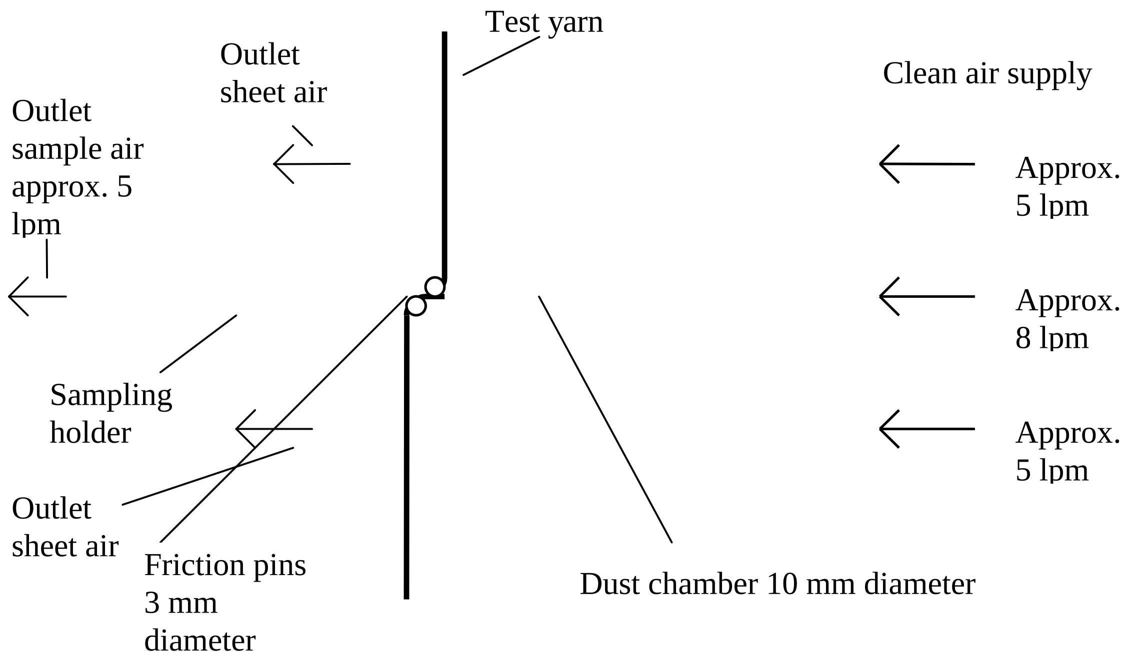


Fig.2 illustrates the double walled dust sampling chamber and the air flow in the sampling region around the friction pins.

The sampling chamber is designed for laminar flow with air velocity of approximately 0.1 m/s to fit the direct reading instruments and sampling filters. The total air flow in the chambers is thus in the range 2-3 l/min. The air was supplied from specially designed absolute filters giving background below the detection level of the instruments [5]. This was two to four orders of magnitude below the background in the surrounding laboratories, and the handling of the yarns thus had to be done with extreme care, i.e. storage in closed bags in order to avoid contamination during measurements.

The effects of mechanical stresses and surface morphological properties and surface treatment on friction stress build up, dust morphology and tensile strength losses were studied.
Pins of diameter ϕ = 3.0 mm, typical for the geometry of textile machinery, of two industrial

fibre guide materials, high carbon low-alloy silver steel and fine grain alumina, DO-Ceram, were used. This choice was also made in order to have materials suitable to be used as model materials.

For the strength loss measurements, controlled technically relevant flaws, light sharp scratches or sharp particles on silver steel were produced by :
i) using marking needles or edges of new 10 mm standard type high speed steel drills loaded only by their own weight, ii) by corrosion due to storage of the degreased pins for four weeks in standard textile lab atmosphere, 65% RH and 20^{o}C.

The measurements were performed in the speed range 10 mm/min to 1000 mm/min. The low speed range was studied for fundamental mechanisms. The high-speed range is approximately that of a warp in a loom. Typically 100 mm/min was used for the strength loss studies.

Strength losses and morphology changes and emission of dust were studied for :

C-fibres : HTA 5331, 200 tex, f 3000 with standard epoxy sizing and in desized condition
IMS, 533, 410 tex, f 12 000 with standard epoxy sizing and in desized condition

Aramide : Kevlar 29, 22 tex, 134-R80-964, in standard sized condition

Evaluation of coefficients of friction was done using equation (5) for the peak values of the measured forces.

$$\ln F_1 - \ln F_2 = 2\mu\theta \qquad (5)$$

F_1, F_2 tensile forces due to friction

The morphology of the fibres and their counterparts were studied by standard scanning electron microscopy technique, i.e. in secondary electron mode with gold sputtered. Tensile testing was done using standard testing methods, i.e.yarn testing for the aramide specimens and impregnated strand testing for the carbon fibres.

RESULTS

Typical surface conditions of polished silver steel pins in fresh and very lightly damaged condition are illustrated in Fig. 1- 4 below.

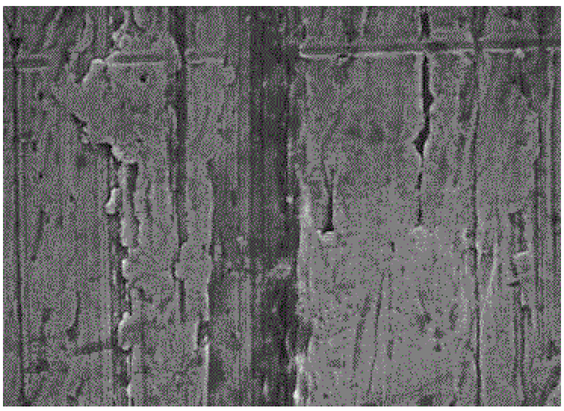


Fig.1 Fresh silver steel, x2000, note the grinding scratches parallel to the sliding.

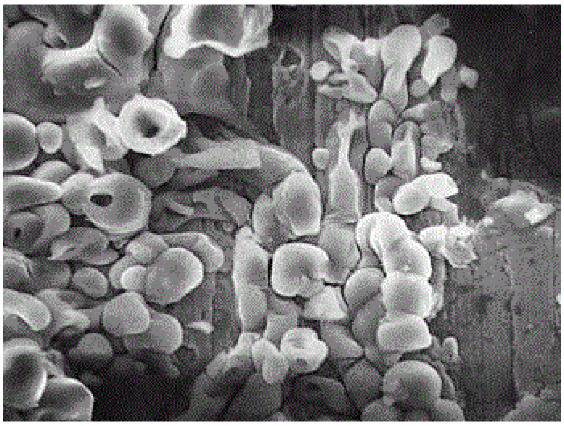


Fig.2 Silver steel with very light corrosiopn particles, x2000, note edges

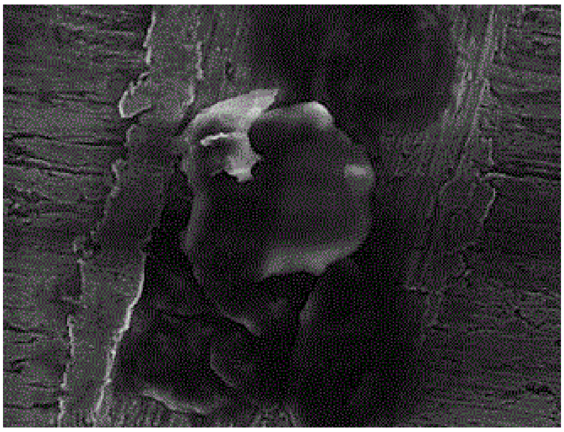


Fig.3. Silver steel with schratch blunted after wear and contmination from C-fibres x2000.

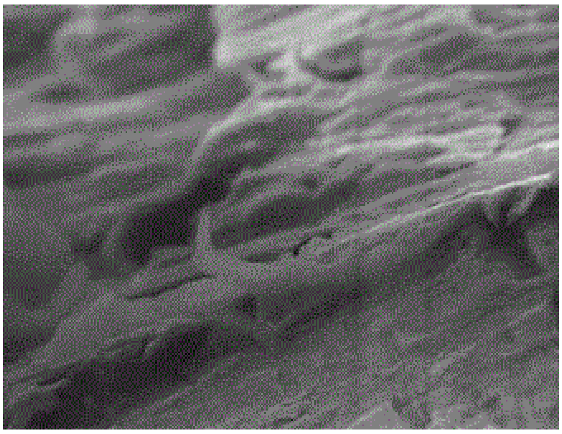


Fig.4 Silver steel with fresh very light scratch, x10000, note the sharpness of the edges.

Morphologies of typical damage on aramide fibres are illustrated in Fig. 5 - 10 below.

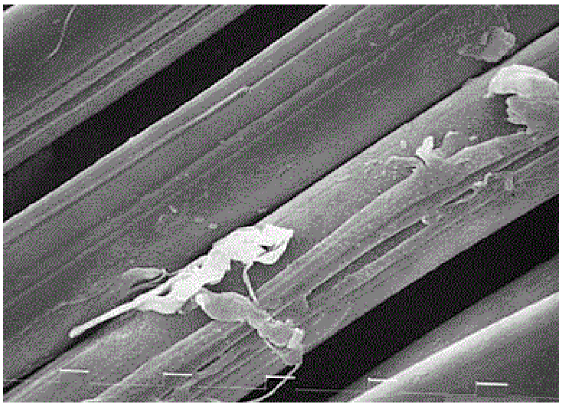


Fig.5. Poughing of aramide on ceramic pin, 2N, 100mm/min, x2000

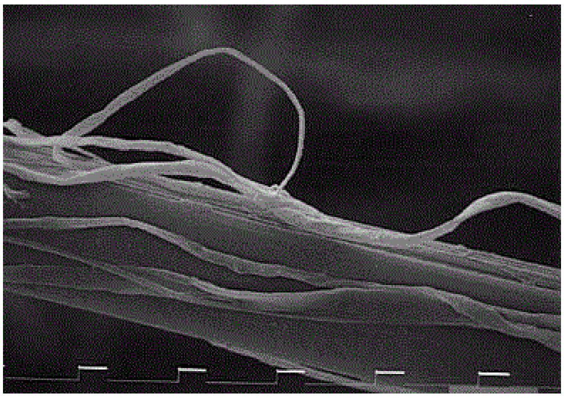


Fig.6. Cutting pattern of aramide, 2N, 100mm/min n a scratched steel pin, x2000

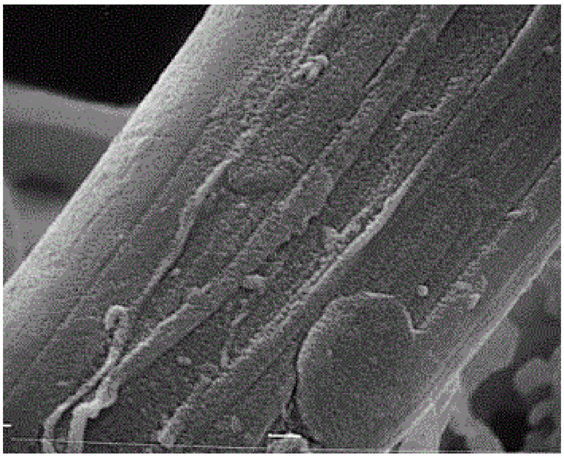


Fig.7. Global shear damage on aramide, 10N on fresh silver steel, x5000

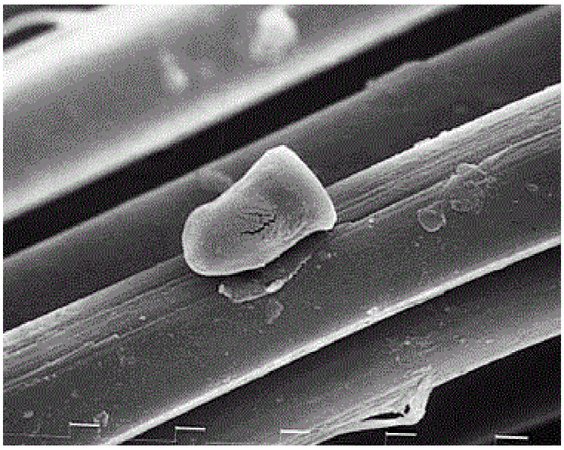
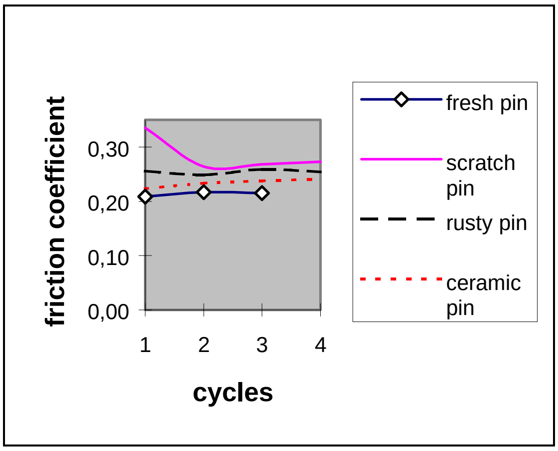
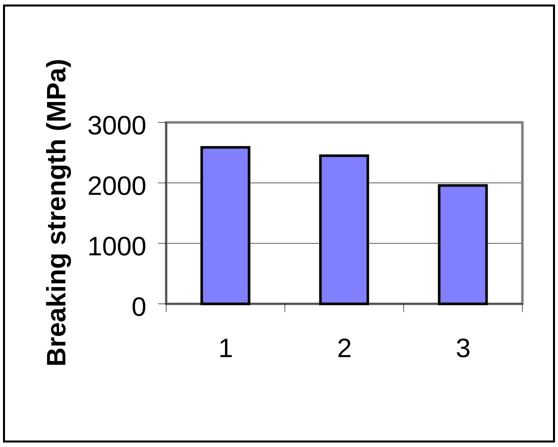


Fig.8 Cutting of a rust particle into aramide, 2N 100mm/min, x200

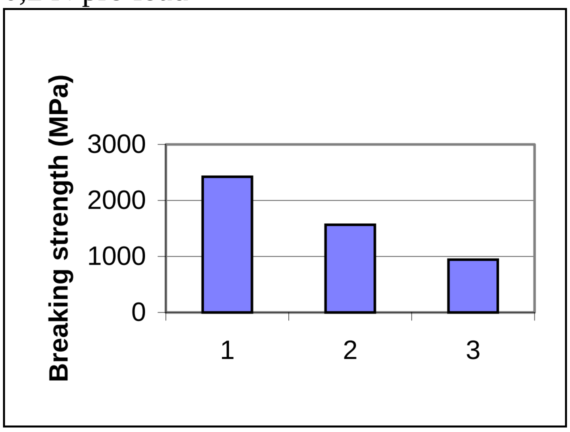
The strength losses of the fibres related to pre-load, the cycles of sliding and surface condition of the contact surfaces for the Kevlar 20 and C-HTA are given in Diagram 1-8 below. The intensities of emission of dust from the C-fibres are given in Diagram 9-11 below.



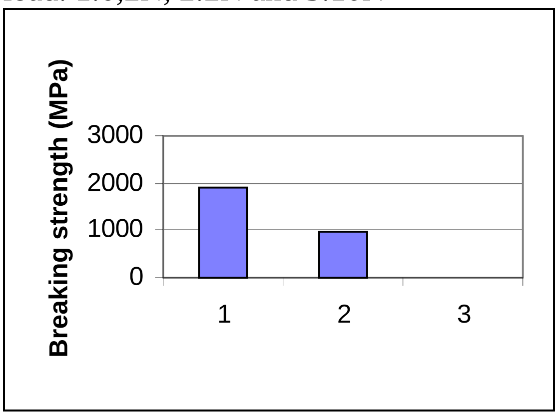
Diagr.1 Coefficients of friction, Kevlar 29 0,2 N pre-load



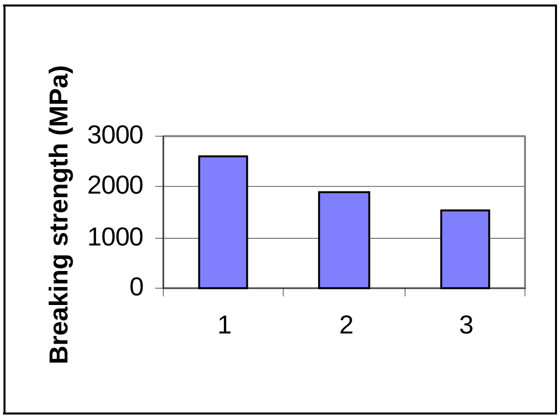
Diagr.2 Kevlar 29 on fresh silver steel, pre-load: 1:0,2N, 2:2N and 3:10N



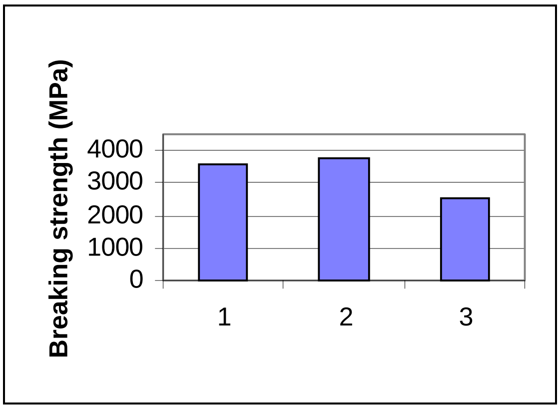
Diagr.3 Kevlar 29 on corroded steel, pre-load : 1:0,2N, 2:2N and 3:10N



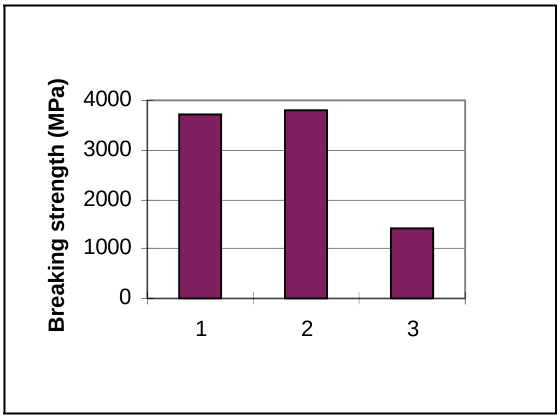
Diagr.4 Kevlar 29 on scratched steel, pre-load : 1:0,2N, 2:2N and 3:10N



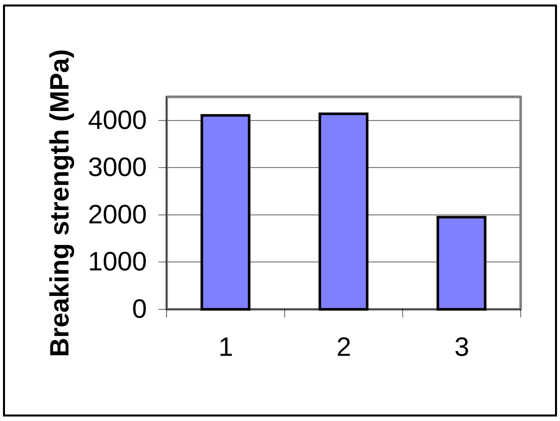
Diagr.5 Kevlar 29 on alumina, pre-load : 1:2N, 2:2N and 3:10N



Diagr.6 Carbon HTA on fresh steel, pre-load : 1:0,2N, 2:2N and 3:1



Diagr.7. Carbon HTA on alumina, pre-load: 1:0,2N, 2:2N and 3:10N



Diagr.8. Carbon HTA on scratched steel, pre-load : 1:0,2N, 2:2N and 3:10N

Diagr.9-11 Emitted particles from individual specimens of MS and HTA and comparison between IMS and HTA carbon fibres

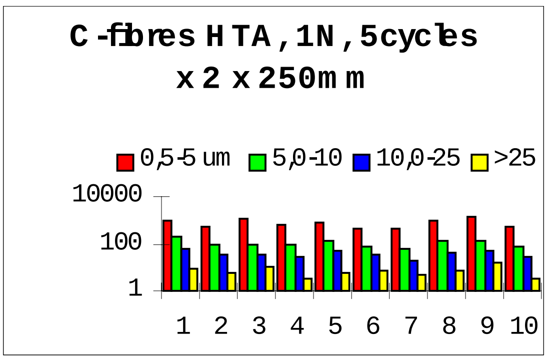


Diagram 9

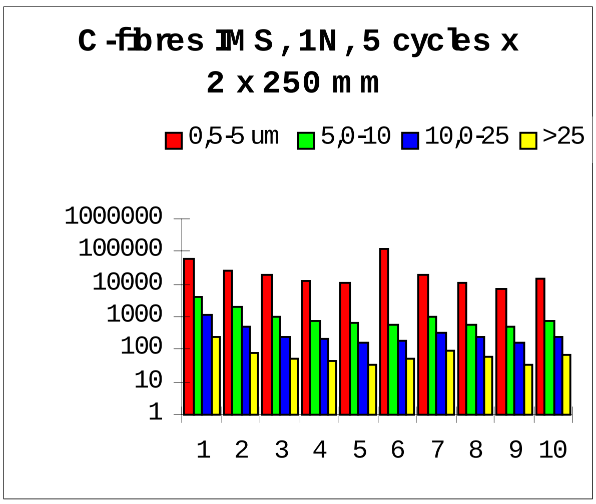


Diagram 10

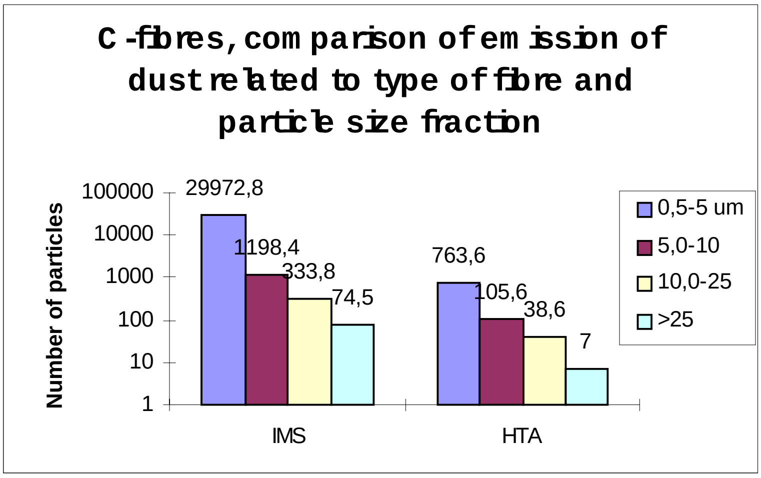


Diagram 11

DISCUSSION

The size of the particles due to the almost invisible very light corrosion and of the sharp raw edges on the silver steel pins were in the same order of magnitude as the diameter of the reinforcement fibres and indicate some limitations for the use of this kind of material as a standard for handleability testing. Thus, controlled careful handling of the counterparts is vital for performance. These limitations do however reflect the realities to be considered in industrial fibre handling. For fundamental studies of sliding friction adhesion force build-up however, for example glass rods of Pyrex and Jena types give consistent performance.

The surprisingly low losses in tensile strength of the tested C-fibres can be explained by the severe wear and blunting of the edges and polishing of the steel pins, the tough sizing eventually covering the edges and the impregnated strand tensile testing, giving the fibre properties in a composite. The IMS fibres with higher tensile strength and modulus but more pronounced anisotropy and lower strength and modulus in compression are known to be more difficult in textile handling than the HT-types, however performed like the HTA-fibres.

Fresh C-fibres gave moderate emission intensities. The IMS-fibres however gave intensities of dust emission a magnitude of order higher than for the HTA-fibres with considerable scatter. The tensile strength and the tensile stiffness are higher for the IMS-fibres. Micromechanical aspects ot the behaviour of fibres of these types are thoroughly discussed in [11]. The very high intensity of dust emission of C-fibres of IM-types reported in [15] can possibly be explained from cross-linking of the sizing of fibre sample being some years old.

The stress build up in anisotropic fibres of yielding types is limited, but the force build up can due to the increase in contact surface due to transverse plasticity be considerable.
The limited strength in shear and compression of the aramide did limit the performance on the surface flaws of the steel and the ceramic pins. These disastrous flaws were barely visible for the naked eye. The conditions for the growth and the morphology of the particles of the beginning corrosion and the sharp scratches however indicate the need of care when handling equipment. The results of the strength loss measurements however also indicate that the damage will be low below some threshold stress level.

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