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KNITTABILITY OF FIBRES WITH HIGH STIFFNESS

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INTRODUCTION

The definition of knitting

Knitting is a family of techniques for production of textile fabrics by inter-looping yarns with the use of hooked needles. New loops are created when the yarns are drawn through the previously formed loops. Knitting techniques and machinery are extensively used for the production of textile products for garment and industrial use. Knitting is also gaining importance for composite materials performing.

Basically two principles of knitting are in use [1-3].
i) Weft knitting gives structures of for example traditional sweaters types suitable for structures taking impact loads.
ii) Warp knitting gives the traditional tricot structures and the non-crimped insert yarn DOS-fabrics extensively used for composite materials fabrication.

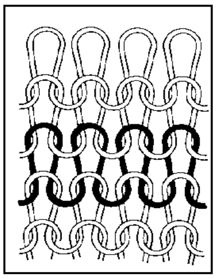

Fig.1: Weft knitted loop structure.

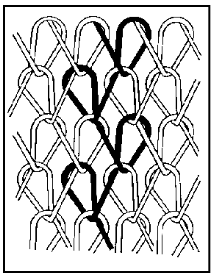

Fig.2: Warp knitted loop structure.

In the knitting process do hooked needles pick up yarns and form closed loops. The stability of the loop formation depends on the bending of the fibres and type of friction on the needles during the different stages of the knitting process. The characteristics of static friction when the yarn is drawn by the needles into the machine, sliding friction in the loop formation and release after loop formation are of vital importance for the final product. The knitting process has however been modelled from first principles using models for friction of fibres on positively curved surfaces and simultaneous plastic deformation.

In weft knitting the yarns are introduced into the inter- looped knit-structure perpendicular to the machine direction, i.e. the weft direction. In warp knitting the yarns are introduced into the inter-looped knit-structure parallel to the machine direction, i.e. the weft direction. The subsequent knitted structures are thus fundamentally different.

In both weft and warp knitted structures rows of loops run across the width of the fabric. These rows are known as courses. Columns of loops that run along the length direction in the structure are referred to as wales [3-4].

Monofilaments and high modulus multifilament yarns known for their high stiffness giving difficulties in knitting process have been studied with respect to:

- Static and dynamic friction
- Bending radius of the fibre during the process
- Adhesion between the needle and the fibre at the gripping and release

This paper presents a method of testing the knittability of yarns with high stiffness in a full down-up cycle in a tensile testing machine of standard type, Instron 1122. The method and the fixtures are based on earlier work by Andersson et.al and are adopted for analysis of the stress build up in fibres or yarns on knitting needles in order to study the knitting process of yarns with high stiffness [5-7].

Spacer fabrics

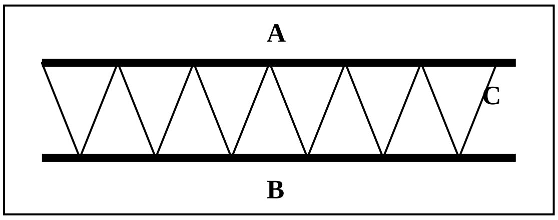

Fig.3: Spacer fabric.

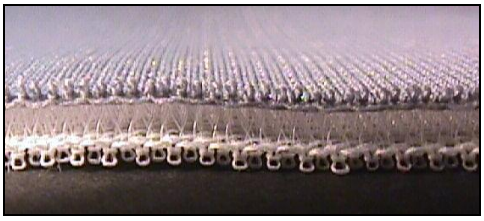

Fig.4: Weft knitted spacer fabric.

Spacer fabric is a type of structure with separate textile layers A and B kept apart from each others with a spacer yarn C, usually stiff monofilaments [8].

Monofilaments and high modulus multifilament yarns are however known for difficulties in the knitting process due to their stiffness. This paper deals with materials for weft knitted spacer fabric structures to be produced on circular knitting machines.

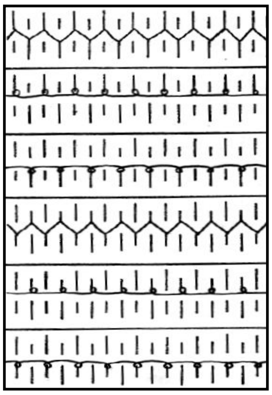

Fig.5: Weft knitted spacer fabric

THEORY OF FRICTION AND BENDING OF FIBRES

The contact stresses in the knitting process are modelled using the drive belt formula and the Herz contact stress relations in the form used by Timoshenko and Goodier [9-12]. Two assumptions used for the first set of equations are:

- R_1, the fibre radius is much smaller than R_2 , the bending radius
- R_2 , the bending radius of the yarn is the same as the radius of the guide or the needle.

These equations used for a first analysis of the frictional stress build up and evaluation of shear stresses from experimental friction force results are however somewhat idealised. The deviations for monofilaments will be discussed later.

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:

$$\Delta\varepsilon = \ln\left(\frac{2R_1 + R_2}{R_1 + R_2}\right) \approx \frac{R_1}{R_1 + R_2} \qquad (1)$$

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. Various models of modes of deformation and bending behaviour of technical fibres are described in [3].

The different types of stress build-up due to bending of fibres depend on their mechanical properties:

a) linear elastic fibres, for example glass and ceramic fibres,

b) fibres with linear elastic behaviour in tension and yielding in compression, for example aramides,

c) fibres yielding in tension and compression, for example textile and steel fibres.

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 are also known to depend on velocity and time.

The following analysis is based on the drive-belt formula with assumed linear elastic properties, negligible stiffness in bending and large bending radii. The stress build up in anisotropic fibres of yielding types is however limited, but the force build up can due to the increase in contact surface due to creep be considerable.

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.

EXPERIMENTAL PROCEDURE

The handleability testing is performed in a rig developed for studies of frictional stress build-up in a standard tensile testing machine [2-5]. Two latch needles of the same type as in the knitting machine are mounted in the rig with the same geometry and motion as in the knitting machine. The total contact angle of the yarn and the distance between the needles can be adjusted to fit the conditions for knitting machines of different gauge numbers. The total contact angle between yarn and needles is set to $\theta = 210^{o}$. The motion is given by the beam of the machine when it moves up and down. The method can in principle be regarded as a modification of the ASTM standard method for testing of friction between yarn and metal.

The merits of this kind of set-up are the possibilities to use an ordinary tensile testing machine and with this rig simulate and identify some of the problems that could occur between needles and yarn in the knitting process. Well-defined mechanical conditions with the static pre-load weight and the possibilities to identify the location of the events of damage on the fibres during the testing of the specimens and to do further examination before knitting are some obvious merits.

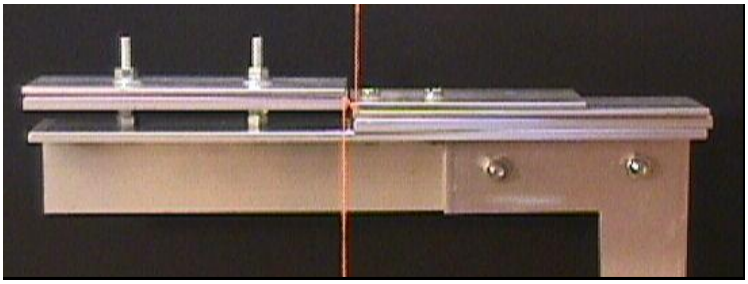

Fig.6: Test rig for frictional stress build-up.

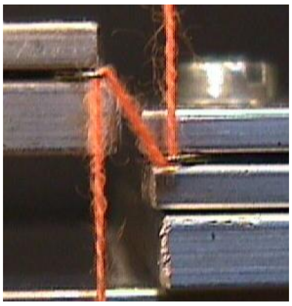

Fig.7: Test rig with yarn and needles

Fig.6-7. illustrate the principle of the set-up for handleability testing with the test rig in a tensile testing machine.

Latch needles of diameter $\phi = 0.4$ mm from a two-bed circular knitting machine gauge E18 was used. The needles were mounted in the rig at the same angle and distance of each other as under the conditions during the knitting process.

The distance between the needles in the rig is 4mm and the movement of the rig in up and downward motion is 15 mm.

The measurements were performed in the speed range 50 mm/min to 1000 mm/min. The low speed range was studied for analysis of fundamental mechanisms of friction and loop formation. The high-speed range is the highest speed possible in the tensile testing machine and below the speed of the yarn in a circular knitting machine, i.e. the range of 150 m/min. These measurements provide important indications about the velocity dependence of mechanical stresses and friction build-up between yarn and needles.

The effects of mechanical stresses, surface morphological properties on friction stress build up and tensile strength losses were studied for polyester and aramide yarns.

The yarns studied:

Polyester monofilament yarns, Reuter Garne GmbH Type FF shrunk with diameters of:
0,08 mm, 0,10mm, 0,12mm 0,15mm

Preload force F_0 : 23mN, 48mN, 78mN, 102mN, 171mN

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

$\ln F_1 - \ln F_2 = 2\mu\theta$	(5)	F_1, F_2	tensile forces due to friction
$\mu = \dfrac{\ln F_1 - \ln F_2}{2\theta}$	(6)	μ	coefficient of friction
$\theta = \dfrac{2\pi}{360^\circ}\left(80^\circ - \theta_{top}\right)$	(7)	θ	contact angle

DISCUSSION

The radii of the needles are of the same order of magnitude as radii of the monofilaments to be knitted for the spacer fabrics. The results of this work illustrates strong influence of the fibre diameter on the knittability.

The coefficients of friction are increasing with increasing load. For multifilament yarns of low bending stiffness, the coefficient of friction is usually higher at low load due to effects of adhesional bonding. The reversed effect of loading is more pronounced for high velocity, thus indicating non-ideal contact between the fibres and the needles.

With sufficient pre-load, the bending radii of the fibres gives strain rate depending, i.e. velocity depending, plastic deformation of the fibres. This mechanism absorbs energy and gives high apparent coefficients of friction.

With insufficient pre-load, the bending radii of the fibres are bigger than the radius of the needles and only point contact is obtained. The assumptions are not fulfilled in this case. From practical point of view, insufficient contact between the needle and the yarn gives insufficient stability of the knitting process.

RESULTS

Results from the measurments are summarised in diagram 1-6 below.

		Velocity mm/min			
		50	200	500	1000
Pre-load mN	23	0,4	0,37	0,43	0,26
	48	0,47	0,42	0,4	0,4
	78	0,55	0,53	0,51	0,5
	102	0,51	0,54	0,54	0,52
	171	0,61	0,57	0,57	0,59

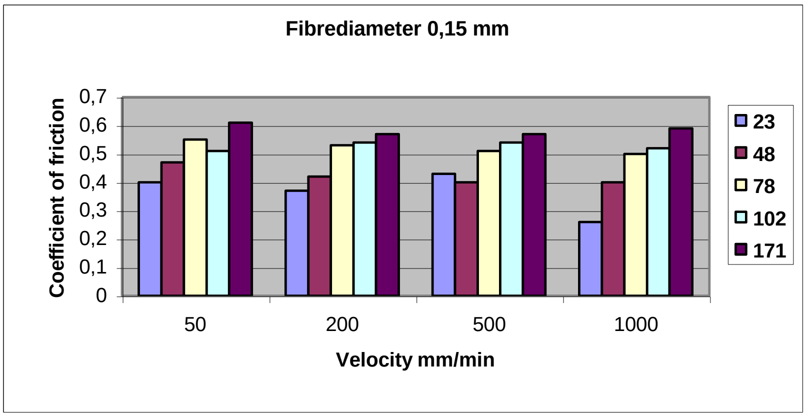

Diagram 1. Coefficient of friction at different velocity and pre-load for fibre diameter 0,15mm.

		Pre-load mN				
		23	48	78	102	171
Velocity mm/min	50	0,4	0,47	0,55	0,51	0,61
	1000	0,26	0,4	0,5	0,52	0,59

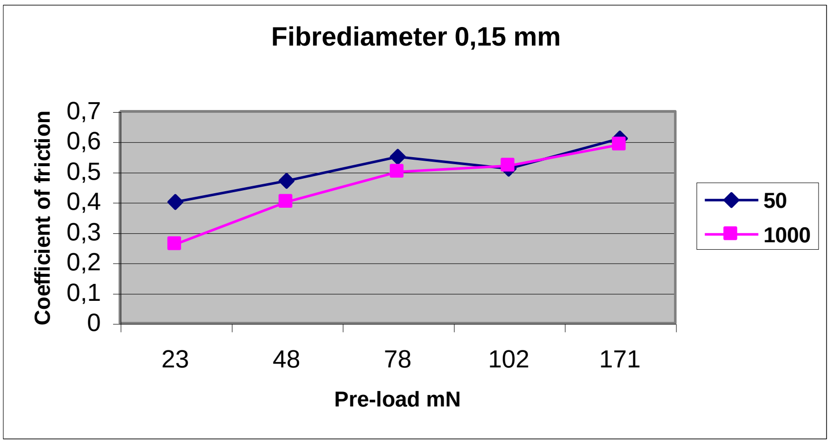

Diagram 2. Coefficient of friction as a function of pre-load for velocity 50mm/min and 1000 mm/min for fibre diameter 0,15mm.

		Velocity mm/min			
		50	200	500	1000
Pre-load mN	23	0,48	0,48	0,49	0,34
	48	0,51	0,52	0,51	0,5
	78	0,54	0,52	0,53	0,49
	102	0,55	0,51	0,51	0,5
	171	0,49	0,48	0,48	0,48

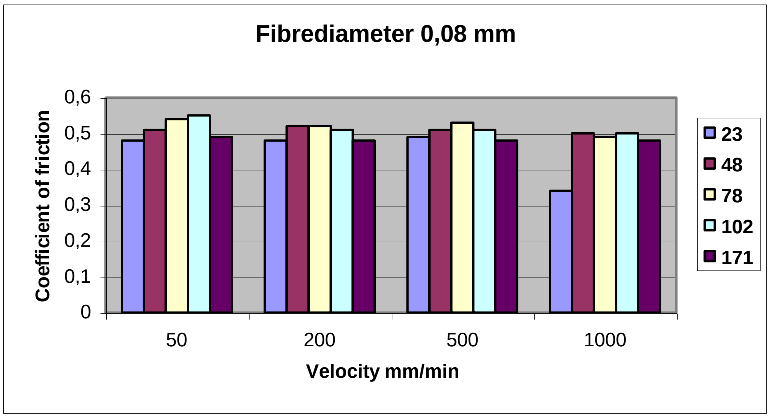

Diagram 3. Coefficient of friction at different velocity and pre-load for fibre diameter 0,08mm.

		Pre-load mN				
		23	48	78	102	171
Velocity mm/min	50	0,48	0,51	0,54	0,55	0,49
	1000	0,34	0,5	0,49	0,5	0,48

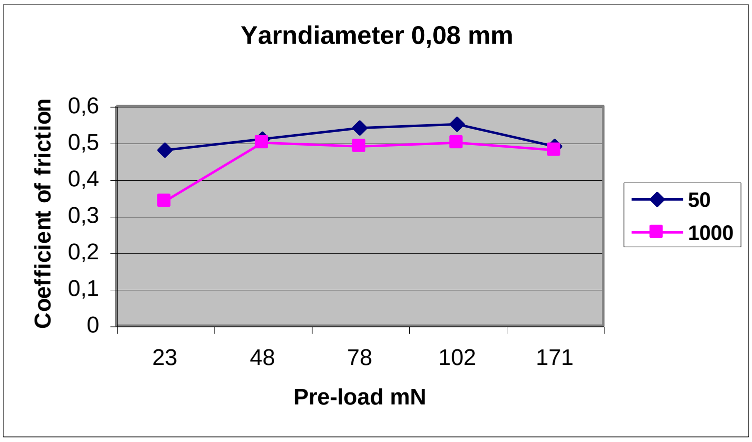

Diagram 4. Coefficient of friction as a function of pre-load for velocity 50mm/min and 1000 mm/min for fibre diameter 0,15mm.

		Fibrediameter mm			
		0,08	0,1	0,12	0,15
	23	0,34	0,43	0,29	0,26
Pre-load mN	48	0,5	0,51	0,45	0,4
	78	0,49	0,38	0,57	0,5
	102	0,5	0,56	0,56	0,52
	171	0,48	0,51	0,59	0,59

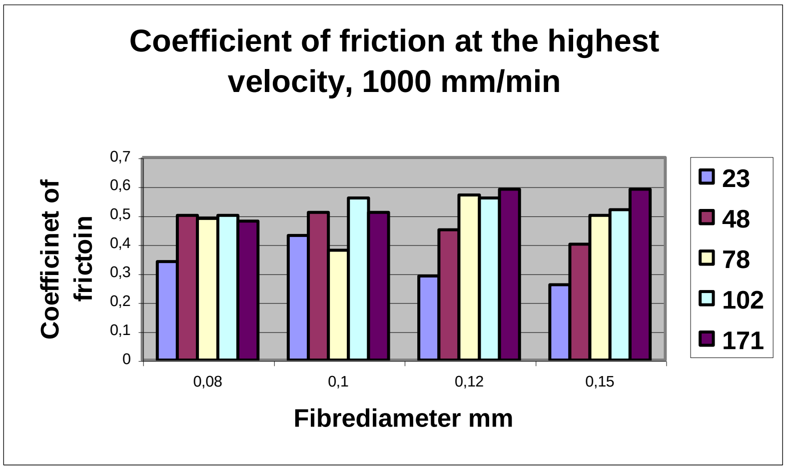

Diagram 5. Coefficient of friction as a function of pre-load and fibre diameter for velocity 1000 mm/min.

		Radius mm		
		0,04	0,06	0,075
	23	0,34	0,29	0,26
Pre-load mN	48	0,5	0,45	0,4
	78	0,49	0,57	0,5
	102	0,5	0,56	0,52
	171	0,48	0,59	0,59

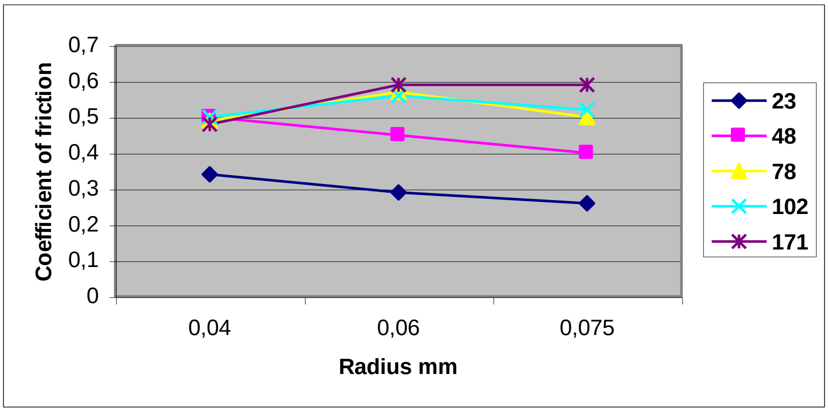

Diagram 6. Coefficient of friction as a function of fibre diameter and pre-load for velocity 1000 mm/min.

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