

AN ANALYSIS OF THE AIR-JET YARN-TEXTURING PROCESS PART III: FILAMENT BEHAVIOUR DURING TEXTURING

M. ACAR, R. K. TURTON, and G. R. WRAY
Loughborough University, UK

ABSTRACT

Experiments performed with a current industrial-texturing nozzle on a specially designed single-head texturing machine are described. These involve the use of high-speed still and cine photography, together with measurements of yarn speed on emergence from the nozzle and yarn-tension measurements at various stages of the process. The results of these experiments provide a better understanding of the filament behaviour during the texturing process. They also provide useful information regarding the effects of texturing speed, overfeed ratio, and texturing with and without water on the mechanisms of the process.

INTRODUCTION

In Part II¹, the characteristics of the air-flow in a currently used industrial-texturing nozzle, namely, the HemaJet, were investigated experimentally, largely by using a scaled-up model. This paper discusses the filament behaviour during texturing; the motion of the filaments induced by the air-flow was investigated by using high-speed still- and cine-photographic techniques and by making filament-speed and filament-tension measurements, with the objective of gaining a better understanding of the mechanisms of the texturing process itself.

Experiments were performed with a standard-core HemaJet texturing nozzle on the single-head research-texturing machine with a 175-dtex/66-fil single-end polyester-fibre yarn.

HIGH-SPEED PHOTOGRAPHY

Photographic Conditions

Studies of the behaviour of the filaments under various texturing conditions involved both high-speed still photography, with an exposure time of 400 ns, and cine photographs taken at 20 000 frames/s, the results being discussed below.

Still Photography

Wetting the filaments during texturing is recognized as one of the essential process conditions to improve the quality of the textured yarn². The effects of wetting the filaments will be investigated in detail in Part V³. In this section, results

of high-speed still photography are reported for both wet- and dry-texturing conditions. Fig. 1(a) typifies a yarn being textured under wet conditions and shows that the loops are being formed as the filaments emerge from the nozzle and that these occupy the lower half of the nozzle outlet (see also Fig. 4 below). It further suggests that, as a result of shortening the over-all length of the yarn owing to the effective loop formation, the tension generated is sufficiently high to pull the yarn close to the nozzle exit in a straightened form.

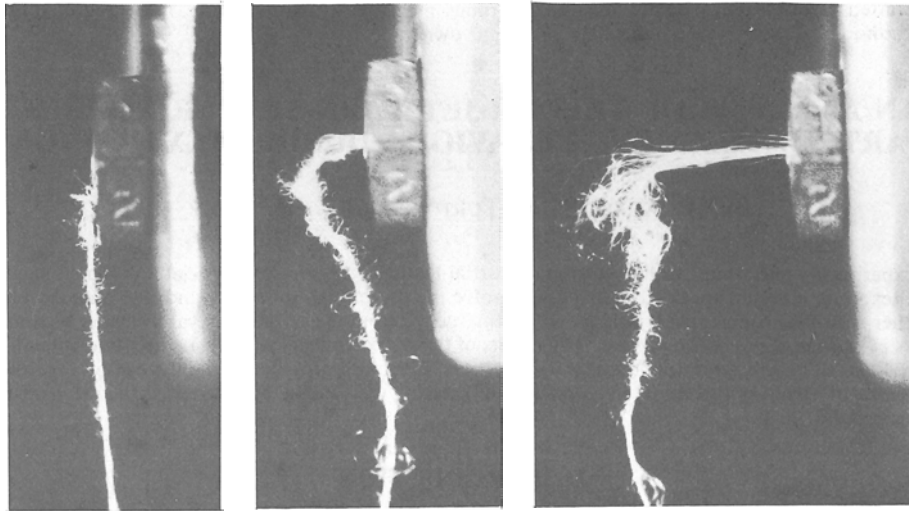


Fig. 1. High-speed still photographs of the emerging filaments during texturing: exposure 400 ns

Conversely, in dry conditions, the overfed lengths of filaments are not completely taken up by formed loops so that loop formation is less effective; the tension in the yarn becomes so low that the textured yarn slackens and is convoluted as shown in Fig. 1 (b). Occasionally, the whole bundle of filaments is blown straight away from the nozzle as a consequence of very low tension in the yarn, due to very poor loop formation, Fig. 1(c) being such an example where the filament separation is seen to be poor; the filament bundle emerges in parallel compact form at about the centre line of the nozzle, where the velocity profile of the air-flow is expected to be reasonably uniform. The forces acting on the individual filament are then approximately equal; hence each filament emerges from the nozzle at about the same speed, which causes scarcely any longitudinal displacement of one filament relative to another, and this mitigates against loop formation.

Cine Photography

All the above observations were further confirmed by high-speed cine photography, which provided even better evidence that the texturing process becomes very unstable when operated dry in that straight, compactly arranged filaments were observed to be frequently blown out from the nozzle. Although it is difficult to demonstrate such results in a paper, Fig. 2 shows prints from high-speed cine films illustrating (a) stable process conditions where the yarn is tensioned and kept close to the nozzle exit by effective texturing; and (b) unstable process conditions where the yarn is blown away from the nozzle.

The Emerging Filaments

In order to obtain greater insight into the mechanism of loop formation, 100 still photographs of both dry and wet texturing were taken and analysed individually. As defined by Fig. 3, the point most remote from the nozzle exit plane at which loops were being formed in each photograph was dimensioned by horizontal and vertical coordinates, x and y (these being the distances from the exit plane and nozzle axis, respectively), and the vertical distance, d , from the nozzle axis to the uppermost filament in the emerging bundle was also measured.

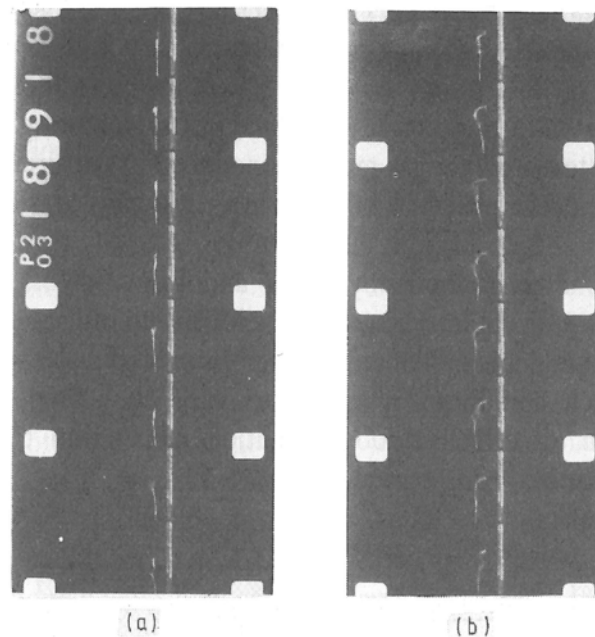


Fig. 2. Prints from high-speed cine films showing filaments in (a) stable texturing conditions, and (b) *unstable* texturing conditions

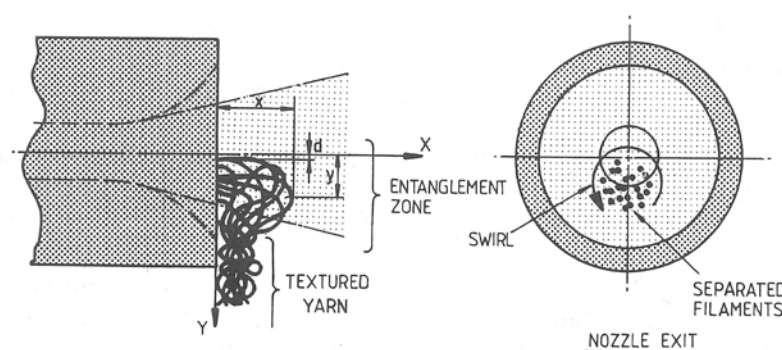


Fig. 3. Schematic representation of the flow and the separated swirling filaments, showing the distances x, y , and d as defined in Section 2.4

The results, summarized in Fig. 4(a) and (b), show that the filaments usually occupy the lower half of the nozzle-exit area when textured dry and do so invariably when textured wet. They also confirm that the filaments are pulled further down and closer to the nozzle exit in wet-texturing conditions than in dry texturing. Shortening of the

over-all length of the textured yarn is more pronounced in texturing wet, owing to the better loop formation achieved. As a consequence, the yarn tension rises, and this in turn pulls the emerging, loop-forming filaments down closely to the nozzle.

Similar observations were made by Bock and Luenenschloss⁴, but they defined 'interlacing' or 'integrating' points usually by referring to still photographs similar to those in Fig. 1(c), which depicts filaments being blown well away from the nozzle exit. As stated above, such conditions give rise to very poor loop formation, so it is misleading to explain an effective loop-formation mechanism by referring to such photographs of inferior texturing conditions.

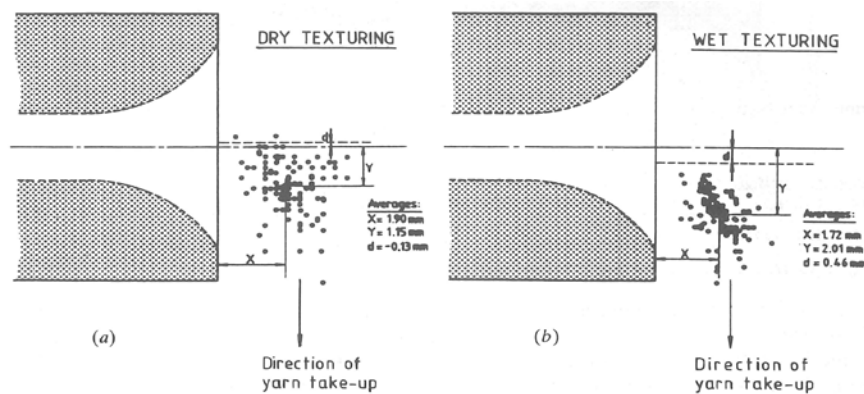


Fig. 4. Results of the analyses of 100 high-speed still photographs each for both (a) dry and (b) wet texturing (dots show x, y co-ordinates).

Free Filament Flow

As was more fully discussed in Part 2, Bock and Luenenschloss⁴ also claimed that: 'There must be a force within the stream that makes the filaments change their direction'. According to their hypothesis, these forces are due to 'pressure barriers' caused by shock waves, and they claim that 'otherwise bending of the filaments would not have been possible'. However, the present authors¹ have shown that no such strong shock waves are observed when the air-flow is disturbed by the presence of the filaments.

Fig. 5 represents three of many high-speed still photographs showing emerging filaments that had been fed to the nozzle direct from a supply-yarn package and allowed to travel in the direction induced by the air-flow only. In none of these photographs were any right-angled turns observed. On the contrary, filaments were continuously blown out of the nozzle by the air-flow, with no diversion from their natural path along the nozzle axis.

It can be concluded that explanations of the mechanisms of loop formation based on the existence of shock waves or of forces in the flow arising from pressure variations causing the filaments to turn at right angles to the nozzle exit are unlikely to be valid.

Filament Separation

Fig. 5(a) shows filaments that are separated and scattered across the nozzle, whereas in Fig. 5(b) they are seen to be poorly separated. These cases correspond

to effective and poor texturing, respectively. Fig. 5(c) shows filaments that are separated as they are emerging from the nozzle, whereas the preceding segments are more closely packed. Such photographs strongly suggest that, for free flow, the opening and scattering of the filaments across the nozzle occur intermittently. They also suggest that fluctuations in the motion of the filaments may lead to the formation of bows and arcs as they are blown out of the nozzle; they may, in addition, appear to form loops. Since the upstream velocity of the air-flow is higher than its downstream velocity, the part of a filament in the upstream flow is likely to be caused to travel faster than its counterpart in the downstream flow, and this will induce the filaments to form bows and arcs along their length in the flow. In addition, variations in the speed of the filaments may occur as a result of the turbulence and also of the non-uniform velocity profile of the flow. The resulting differences in the magnitudes of driving forces then act on the individual filaments that are continually changing their locations across the nozzle.

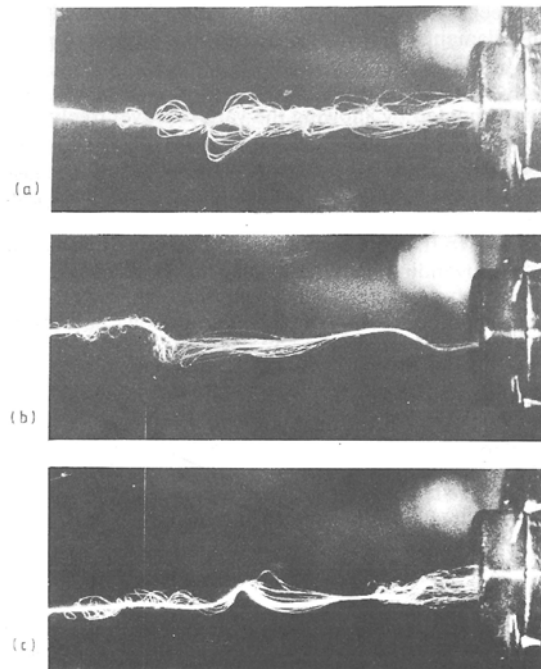


Fig. 5

Fig. 5. High-speed still photographs showing the free filament flow from a standard-core HemaJet

Examination of the yarns after being blown away from the nozzle showed that, in fact, no loops were formed in the filaments; the only intermittent filament separation to be observed was in the form of randomly scattered balloons along the filaments, which disappeared under a slight tension. This provided further evidence for the intermittent occurrence of filament separation, and it can be concluded that loop formation may occur only when the filaments are separated and that a better separation of the filaments is essential for effective texturing.

FILAMENT SPEED

Since the yarns are overfed into the nozzle, some excess lengths of filaments are free to travel at a speed induced by the supersonic, turbulent, and non-uniform air-flow¹. The speeds of some filaments during texturing may approach that of free filaments in an air stream and may approach the air velocities if frictional losses are small. Non-uniform velocity distribution of the air-flow, turbulence, swirl imparted to the filaments, friction between the filaments themselves, and friction between the filaments and the contacting surfaces will cause variations and fluctuations in the individual filament speeds across the nozzle, and these in turn will cause longitudinal displacements of the filaments relative to each other as suggested previously by one of the present authors⁵.

It was not practicable to measure the speeds of individual filaments, but their maximum speed was estimated by allowing the yarn to travel freely in the air stream by feeding it into the nozzle direct from a supply-yarn package in as tension-free a condition as possible. The emergent filaments were collected for a timed period and weighed to give an approximation to the maximum speed likely to be attained by individual filaments.

Unfortunately, owing to the very fast unwinding speeds, it was difficult to eliminate friction between the unwinding yarn and the supply package; hence the speeds measured by this method could be much lower than the maximum filament speeds under actual texturing conditions. Nevertheless, Fig. 6 shows how the yarn speed varies with the air pressure for a free flow of yarn. It will be noted that, in spite of the frictional losses during unwinding, these values of speed are very much higher than typical yarn-texturing speeds of 400 m/min. Had there been no functional losses, it is estimated that the actual filament speeds could be an order of magnitude greater than the typical yarn-texturing speeds or even higher, since the ratio of air velocity to the typical yarn-texturing speed is about 50.

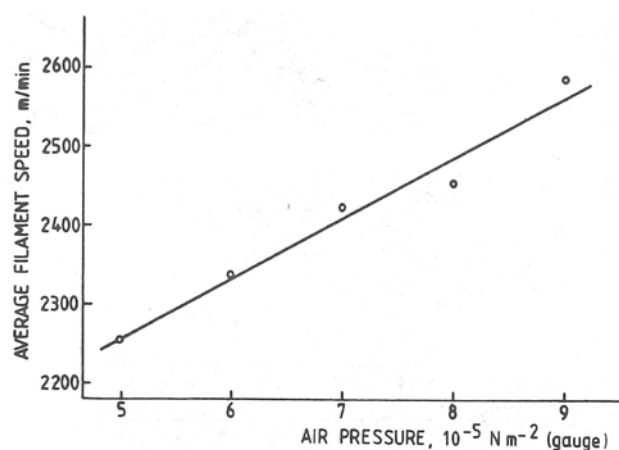


Fig. 6. Average yarn speed in the air-flow for varying air pressure and unconstrained yarn supply

TENSION IN THE YARN DURING TEXTURING

Assessment of Tension and Loop Formation

An examination of the structure of air-textured yarns shows that they usually consist of randomly distributed looped sections followed by adjacent sections of virtually straight parallel filaments possessing very few loops. The looped sections occur more frequently in yarns textured under wet conditions (effective texturing) than those textured under dry conditions (poor texturing). This suggests that loop formation may be an instantaneous process that occurs intermittently, as discussed in previous sections, and then causes the yarn tension to increase as the loops are formed. Fluctuations in the yarn tension in the texturing zone could thus provide evidence regarding the frequency of loop formation.

The average value of the tension in the yarn is another useful property that could provide information regarding both the effectiveness of the texturing and the stability of the loops produced. Since the tension generated in the yarn between the nozzle and the delivery rollers arises from the loop formation, it is an indication of the effectiveness of the texturing. Moreover, because less stable loops are removed under applied loads whereas more stable loops offer a resistance that gives rise to increased tension in the yarn, an indication of the stability of the loops formed during the process can be obtained by measuring the tension in the stabilizing zone, provided that the stabilizing ratio is kept constant.

Tension Fluctuations

The frequency response of the only available yarn tensiometer (Rothschild R-1092) was limited to 300 Hz, which was insufficient to respond to the high frequency of tension fluctuations during texturing. Such fluctuations had therefore to be assessed from the detailed analysis of the high-speed cine films.

Tension in the textured yarn is expected to vary inversely with the maximum distance between the blown-out filaments and the nozzle-exit plane, and variations in this distance should therefore reflect fluctuations in tension. This distance, x , as shown in Fig. 3, was measured for 100 consecutive frames of high-speed cine films by using an image analyser, and Fig. 7(a) and (b) shows these fluctuations for dry and wet texturing, respectively. The other processing parameters were: air pressure 900 kPa (abs); texturing speed 450 m/min; and overfeed ratio 20%. One hundred frames of the high-speed film correspond to 0.005 s of the process, which therefore corresponds to a length of 37.5 mm of the textured yarn.

Fig. 7(a) and (b) suggests that the frequency of fluctuation of the distance from the nozzle exit during wet texturing is much higher than that during dry texturing but with a smaller amplitude of oscillations. The mean maximum horizontal distance, x (see Fig. 3), for wet texturing (1.43 mm with a standard deviation of 1.67) is smaller than that of dry texturing (2.18 mm with a standard deviation of 1.02), which thus confirms the observations made in Section 2.4 from the high-speed still photographs (see Fig. 4).

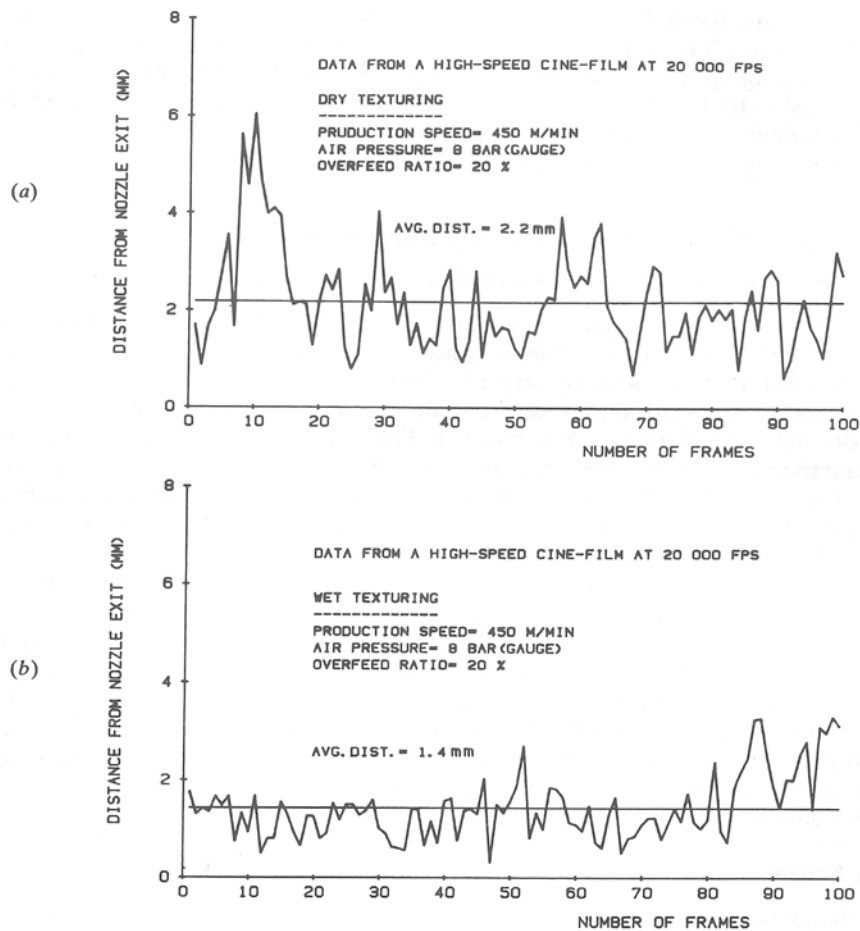


Fig. 7. Variation of distance x (as denoted in Fig. 3) for 100 consecutive frames, indicating tension variations in the delivery zone

Average Tension

The average tension in the yarns, in both the delivery and stabilizing zones, was measured by the Rothschild Tensiometer, and the results are shown in Figures 8-10 for varying texturing speed, air pressure, and overfeed ratio, respectively. A general observation is that both the effectiveness of the loop-formation process (as measured by the average tension in the delivery zone) and the stability of loops (as indicated by the average tension in the stabilizing zone) are much higher for wet texturing than for dry texturing, which thus provides further support for the comments based on the photographic studies reported in Section 2.

Fig. 8(a) shows that the yarn tension in the delivery zone reduces with increasing texturing speed, which indicates a slight drop in the effectiveness of texturing. At the higher speeds, the reduced tension allows the filaments to be blown well away from the nozzle, and these results in unstable texturing and the eventual breakdown of the process. For dry-texturing conditions, this breakdown occurred at lower speeds, texturing being impossible at 600 m/min, although it was possible under wet-texturing conditions. However, Fig. 8(b) shows that the stabilities of the loops, as indicated by the stabilizing-zone tension, are significantly affected by the texturing speed, and decrease with increasing speed. It can be concluded that, although the effectiveness of texturing is reduced only slightly by increasing the texturing speed,

the loops formed at high speeds are unstable and can be removed under tension applied in the stabilizing zone.

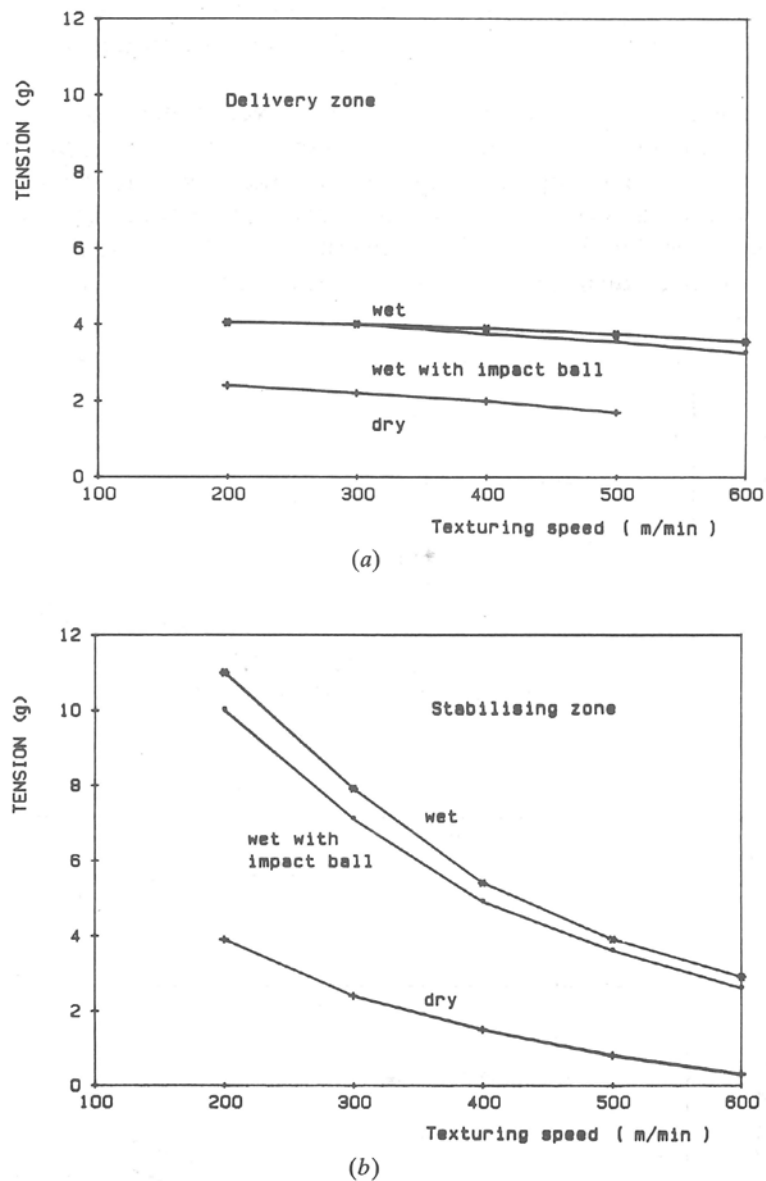
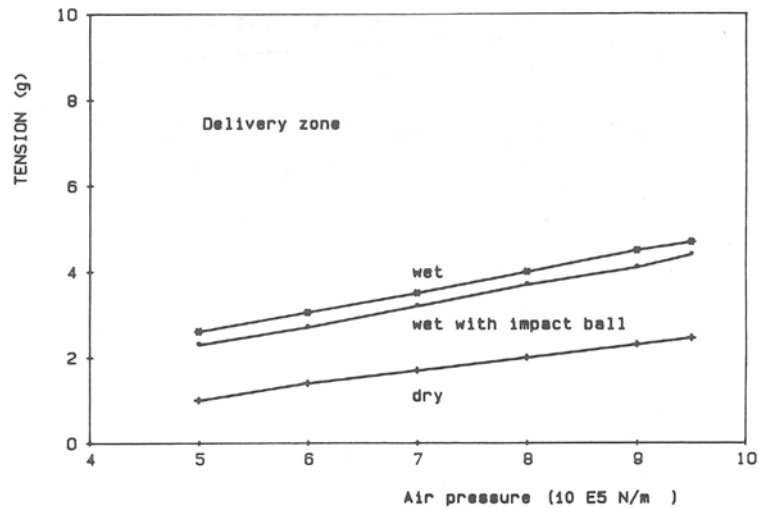
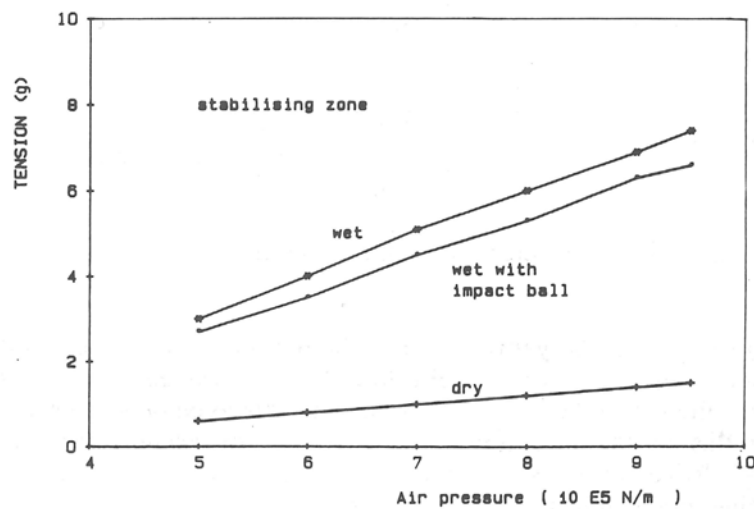


Fig. 8. Variation of tension with texturing speed in the delivery and stabilizing zones

Fig. 9(a) shows that the yarn tension in the delivery zone increases with increasing air pressure. This is not surprising, since the higher the working pressure, the higher the air velocity becomes, and consequently filaments will travel at higher speeds. Furthermore, owing to increased turbulence giving rise to greater variations in the velocity distributions, longitudinal displacements of the filaments relative to each other are increased. This in turn allows more frequent loop formation, and more effective entanglements, leading to increased texturing and higher levels of stability (Fig. 9(b)).



(a)

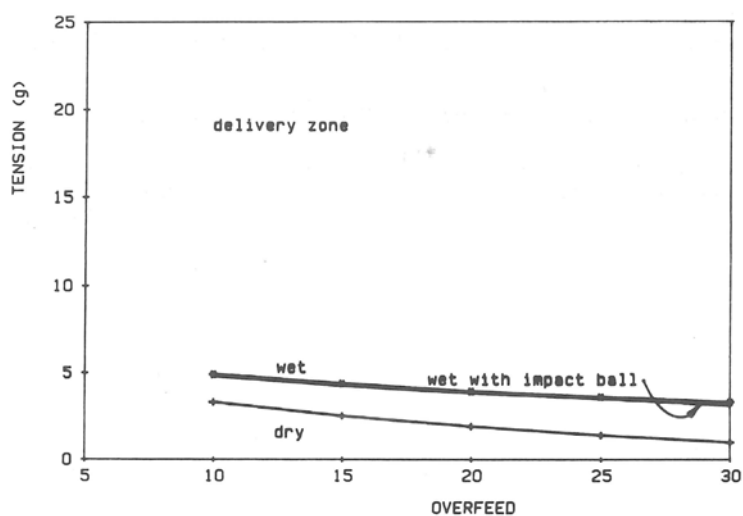


(b)

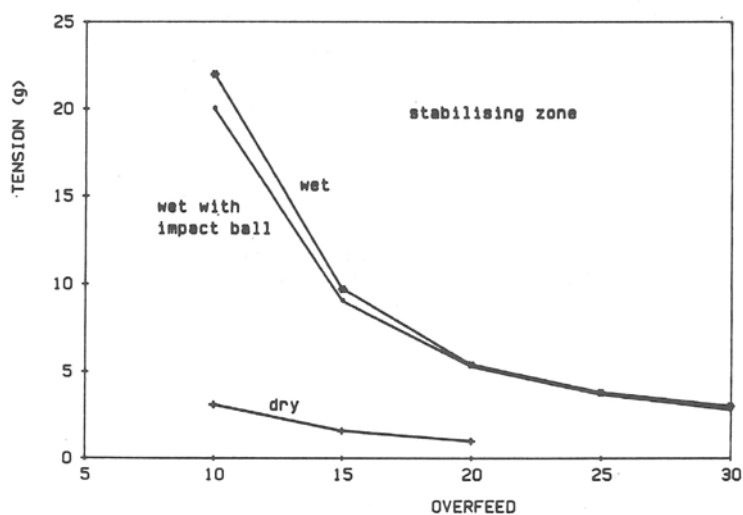
Fig. 9. Variation of tension with air pressure in the delivery and stabilizing zones

Fig. 10(a) shows that the delivery-zone tension reduces slightly with increasing overfeed ratio, which indicates a loss in the effectiveness of texturing. This is due to the excessive lengths of the filaments, which cause larger loops and a slacker yarn core to be formed, which in turn reduces the yarn stability (Fig. 10(b)). At high overfeed ratios, the process becomes unstable and eventually breaks down. This unsatisfactory stage is reached at lower ratios for dry texturing.

Fig. 10(b) also suggests that the stability of the loops is significantly higher at low overfeed ratios and that stability reduces rapidly for increasing ratios. However, the process fails to produce acceptable textured yarns at low overfeeds. In particular, the number of loops formed is fewer, as was shown by one of the present authors⁶, because there are insufficient excess lengths of filaments to form such loops. Such yarns produced at low overfeeds, when tested in static-stability tests, also exhibited high apparent stability, as will be shown later in Part VII⁷. However, stability tests would be expected to give misleading results by yielding high stability values for yarns produced at low overfeed ratios, which cannot be textured effectively.



(a)



(b)

Fig. 10. Variation of tension with overfeed ratio in the delivery and stabilizing zones

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