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AN ANALYSIS OF THE AIR-JET YARN-TEXTURING PROCESS PART I: A BRIEF HISTORY OF DEVELOPMENTS IN THE PROCESS

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ABSTRACT

After a brief description of the air-jet texturing process, the historical development of industrial texturing nozzles is summarized, and a critical review is given of previous investigations that have been directed to an understanding of the texturing process. It is argued that many of the previous hypotheses were based on a technology that used pre-twisted supply yarns and that they are invalid for current zero-twist texturing processes.

THE PROCESS

The requirements for air-jet texturing are illustrated schematically in Fig.1. The process involves the 'overfeed' principle, whereby the multifilament supply yarn, provided 'over-end' from a creel, is fed into the nozzle at a greater rate than it is taken away. To achieve this degree of overfeed, the yarn passes through the feed rollers W1.1 or W1.2 or both faster than it does through the delivery rollers W2. When the overfed filaments enter the nozzle, they are carried along through the nozzle, blown out from the texturing end, and formed into textured yarn by the effect of the air stream provided by a compressed-air supply.

The zone between the feed rollers and the nozzle is termed the *feed zone* and the zone between the nozzle and the delivery rollers the *delivery zone*. The supply yarn is normally wetted just before it is fed into the texturing nozzle by passing it through a water bath or through a wetting unit, which can either be separate or integrated in the nozzle assembly (wet texturing apparently improves the quality of the yarn produced). Texturing nozzles are usually enclosed in a chamber, not only to reduce the noise created by the air-jet, but also to collect the used water and some of the spin finish washed away from the filaments during the process.

Some texturing nozzles have an impact element at the nozzle exit, to be used optionally in certain cases recommended by the manufacturer. (This can have one of several different shapes, i.e., cylindrical, flat, or spherical, as shown in the HemaJet design in Fig. 2.) The element is believed to improve the process stability and yarn quality in the texturing of certain yarns.

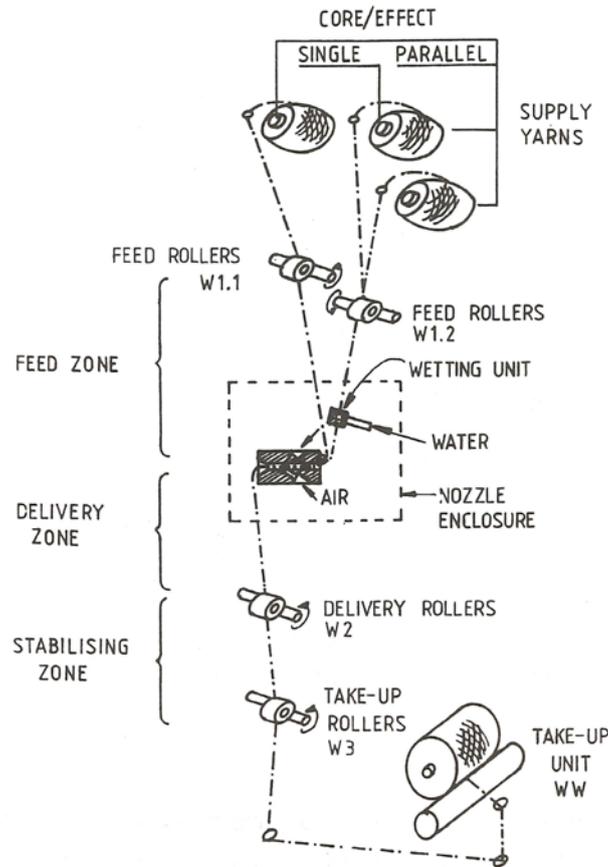


Fig.1. Schematic illustration of the air-jet texturing process as used in the current research

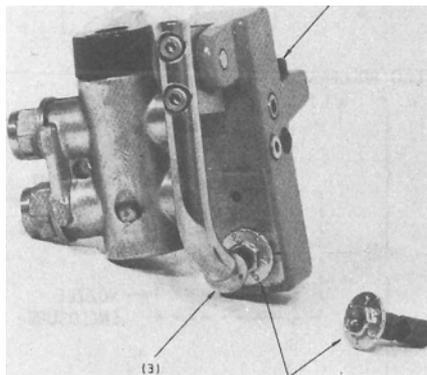


Fig.2. The HemaJet, an industrial texturing nozzle, showing the standard nozzle core (1), integrated wetting unit (2), and impact element (3)

As well as a single supply yarn, two or more yarns of the same or different types can be textured at different speeds (core-and-effect texturing) by the use of separate feed rollers, W1.1 and W1.2. Another set of take-up rollers, W3, running at slightly higher speeds than the delivery rollers, W2, are used to apply tension to the textured yarn in

order to stabilize the loops formed during the process, the zone between these two sets of rollers being termed the *stabilizing zone*. The textured yarn is then wound up by means of a high-speed take-up unit, WW. Heaters can be optionally used in the stabilizing and take-up zones to impart further desired properties to thermoplastic filament types.

INDUSTRIAL-NOZZLE DEVELOPMENTS

The air-jet texturing process spans three decades, and in that time it has seen many improvements in the process and many variations in nozzle design. The heart of the air-jet texturing process is the texturing nozzle. This may vary in design and details but remains unchanged in its underlying principles. Fig. 2 shows an example, the HemaJet, a typical industrial texturing nozzle.

Piller¹ claims that one of the earliest air-jet texturing nozzles, as shown in Fig. 3, was used on a standard ring-twisting machine in Czechoslovakia; the air emerging from the annulus entrains the yarn and blows it against a 'bridge' (an impact element), where the yarn is separated and formed into loops. However, it is doubtful whether the Czechoslovak jets were earlier than the rather similar nozzle (Fig. 4) that was patented by du Pont² in 1952. The best-known duPont Taslan Type 9 nozzle³ was introduced in 1954 and was used until the early 1970s. The Taslan process consisted in overfeeding the multifilaments into the nozzle by means of a stepped hollow needle inclined at 45° to the nozzle axis, the air entering axially as shown in Fig. 5(a). Normally, this nozzle was positioned with the nozzle axis in the vertical plane, but it is here shown in the horizontal plane so that its different yarn-feed and air-supply arrangements can be compared with those of the other nozzles illustrated.

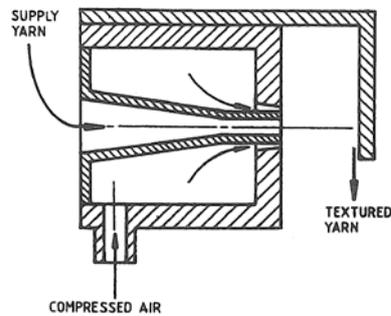


Fig. 3. An early texturing nozzle (Czechoslovakia)

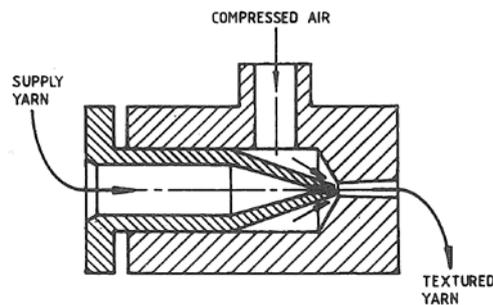


Fig. 4. An early duPont texturing nozzle (U.S.A.)

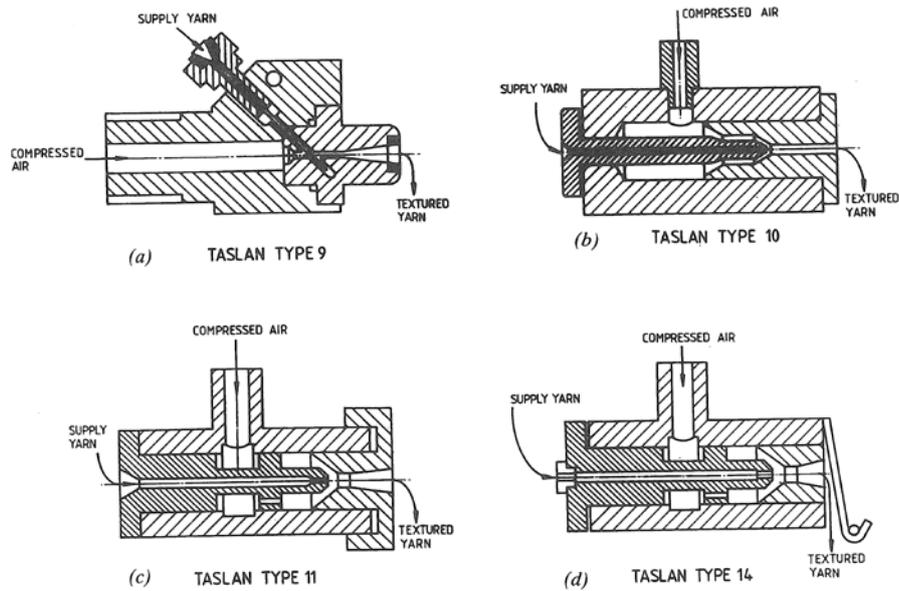


Fig. 5. The duPont (U.S.A.) Taslan texturing nozzles

The duPont Type 10 nozzle⁴, introduced in 1960, had the overfed yarn entering a needle with the air-flow passing through a uniform gap around the needle circumference, as shown in Fig. 5(b). The Type 11 nozzle⁵, introduced in 1961, had several design changes, including that of feeding the air through an inlet hole displaced to one side (Fig. 5(c). The Type 14 nozzle⁶, introduced in 1973, was very similar except that a plate was situated at the exit to make impact with the air flow and the emerging yarn as shown in Fig. 5(d).

Fig. 6 shows a nozzle, different in construction but similar in principle, that was introduced in the 1950s in Czechoslovakia to make Mirlan yarns⁷. The texturing nozzle was designed in such a way that three air inlets were inclined so as to cause the air-flow to carry the yarn on its path through the nozzle. In later versions of the Mirlan nozzle, an impact element, which did not appear in the early models, was attached to the nozzle exit.

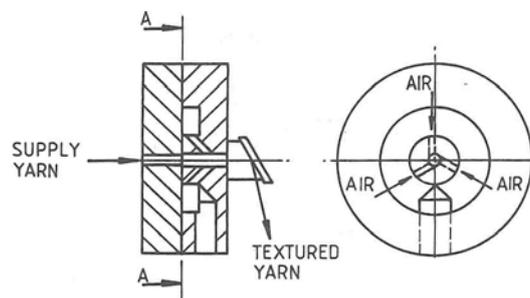


Fig. 6. The Mirlan texturing nozzle (Czechoslovakia)

A nozzle similar in construction was introduced by the Heberlein Company of Switzerland in the late 1970s under the trade name of HemaJet⁸. The air was fed into the main duct of the nozzle by means of three small inlet bores, where it impinged upon the overfed supply yarn from three sides as shown in Fig. 7. Radially equispaced air-inlet bores were axially staggered and made an angle of approximately 48° with the axis of the main duct.

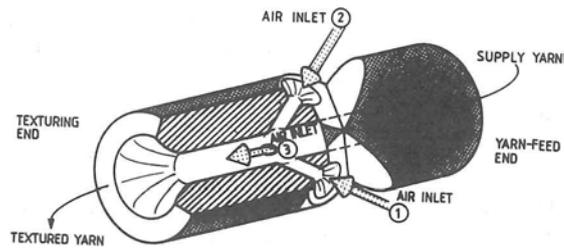


Fig.7. The HemaJet texturing nozzle (Switzerland)

Several other nozzles that have been used have not been reviewed in this section, but the underlying principles of all texturing nozzles have remained unchanged, with only slight differences made in their detailed construction. However, all texturing nozzles can be categorized into two groups according to their structures:

- (i) converging-diverging (de Laval) types of nozzle, i.e., a converging-diverging nozzle is situated at the yarn-exit end of the nozzle assembly, e.g., duPont's Taslan Type 14 nozzle; and
- (ii) cylindrical nozzles, i.e., one or more air inlets opening at an angle to a cylindrical straight uniform main-flow duct of the nozzle, e.g., Heberlein's HemaJet.

The progressive development in nozzle design since the early 1950s has considerably improved the productivity of the nozzle and has led to:

- (i) increased texturing speeds from about 50 to about 500 m/min;
- (ii) reduced compressed-air consumption from about 22 to about 12 m³/h per jet;
- (iii) reduced energy consumption by about 50%;
- (iv) elimination of the necessity for a pre-twisted supply yarn; and
- (v) improved yarn quality.

These improvements have reduced the conversion costs of air-jet textured yarns to a level comparable with those of cotton- or wool-spinning processes^{9,13} and consequently have led to a current upsurge in interest in the air-jet texturing process, both in industry and in research institutions, owing to its unique capability to produce textured yarns that closely simulate spun yarns.

REVIEW OF PREVIOUS INVESTIGATIONS INTO THE TEXTURING MECHANISM

There is a scarcity of published knowledge about the texturing mechanism, particularly the relation between the air-flow and the mechanism of loop formation. Publications in the 1960s by Wray^{14,15} and by Wray and Entwistle^{16,17} were followed by those of Wray and Sen¹⁸⁻²⁰, Sen²¹, and Sivakumar²² in the early 1970s. The mechanisms claimed by these researchers were all based on the use of pre-twisted yarns and are therefore not valid for to-day's no-twist yarn-texturing process. Further research by Bock and Luenenschloss²⁵⁻²⁷ in the early 1980s claimed that loop formation mainly resulted from the retardation of the filaments by shock waves, but this was not entirely new since Sen²¹ had observed such shock waves in 1970, and Sivakumar²² in 1975 had suggested a similar mechanism based on his theoretical work and Sen's experimental findings.

Wray¹⁴ analysed the structure of air-jet textured yarns by tracer-filament and other optical techniques and observed that a longitudinal displacement of the filaments relative to each other occurred during the process. Wray¹⁵ also studied the effects of process parameters, namely, overfeed ratio, air pressure, texturing speed, filament linear density, and supply-yarn pre-twist, on the properties of the yarn produced. In the 1960s, the first researchers to analyse the mechanism of the air-jet texturing process with a Taslan Type 9 nozzle were Wray and Entwistle^{16,17}. They observed the false-untwisting of the filaments during the process with the aid of high-speed photography. They studied the air-flow and related the vortex shedding in the flow to the untwisting of the yarn. They also analysed the effect of the needle setting with a Taslan Type 9 nozzle and a modified Type 9 nozzle. Their postulation of the texturing mechanism was based on the untwisting and retwisting of the over-fed filaments, as follows¹⁶:

'The most significant observation has been the rotational nature of the turbulent air stream. This gives rise to a false-twisting action such as would untwist the yarn temporarily during its passage through the jet and thereby cause an opening of the multifilament structure for the overfeed to take effect. The filaments are first convoluted into U-shaped waves, which in turn snarl into looped coils owing to the twist-liveliness of the slackened filaments'.

This hypothesis presupposed that a vortex-shedding action was occurring in the venture to cause the observed rotations of the textured yarn.

In 1970, Sen²¹, working under Wray's supervision, analysed the texturing mechanism by using a scaled-up model of the Taslan Type 9 nozzle and showed that the yarn structure inside the nozzle was open and the texturing was seen to occur at the nozzle exit. He also claimed that the periodic shedding of the vortices in the wake of the yarn-feed needle, as postulated by Wray and Entwistle¹⁶, could not exist at the highly turbulent flow with high Reynold numbers that he verified by measurements. He concluded that the previously suggested false-untwisting vortex mechanism was invalid, although the over-all principle of texturing by a temporary removal and reassertion of the twist was still applicable. An alternative hypothesis of loop formation based on false-untwisting was suggested as follows²¹:

'The highly turbulent air-flow blows the overfed parent yarn out of the jet, and this causes the portion of the yarn immediately following it (i.e., that just entering the jet) to be in high tension. As the variation in mean flow velocities is high, this occurrence continues intermittently. Thus there is an intermittent fluctuation of tension in the overfed yarn entering the jet. At the exit of the jet, the yarn changes its path abruptly as it is withdrawn from the jet at a right-angle to the jet axis. Due to the momentum of the blown-out yarn, the end of the yarn being withdrawn from the jet exit is subjected to an alternating force at right angles to its axis (i.e., an alternating torque). As a result of this, a false-twisting effect is created such that it untwists the portion of the parent yarn inside the jet and thus its structure is opened. Then, when the opened overfed yarn is blown out of the jet, the extra available filament lengths snarl into a looped and entangled state at the jet exit under the extremely violent (turbulent) nature of the flow'.

Like Wray, Sen used high-speed photography. However, he was also able to show, for the first time, that shock waves occurred in the flow just outside the nozzle; this was observed by Schlieren photography²¹ and the photographs have only recently been

published more widely^{23,24}.

Their various analyses of the air-jet texturing process led Sen and Wray¹⁸ to develop an apparatus for manufacturing yarns of the air-jet-bulked type without the use of air. They claimed that the properties of these yarns were generally comparable with those of other air-jet-textured yarns and that these were related to common features in their physical structures²⁰, but, as with the known air-textured yarns at that time, pre-twisted supply yarns were used,

In 1975, Sivakumar²² interpreted Sen's findings in a slightly different way and extended the research into the use of a nozzle based on the principles of the Taslan Type 10 nozzle.

He verified the existence of shock waves in the flow by theoretical means and concluded that these played a very important role in loop formation by forming a 'pressure barrier' and retarding the filaments at their place of occurrence. He based his hypothesis of the texturing mechanism on the effect of shock waves on the filaments and stated²² that:

'When a highly pre-twisted yarn is overfed into the jet, it comes under the influence of the air-flow in the jet and travels along with it. When it reaches the place where the shock waves occur, it comes under the influence of the "pressure barrier", which suddenly retards the yarn. This reduces the tension⁷ in the yarn suddenly and the filaments in the yarn tend to snarl and form loops over the snarled length. This along with the turbulence of air causes the yarn to texturize'.

All of these hypotheses were based on the assumption that the supply yarns were pre-twisted. Hence, without reference to any other aspect of the process, these hypotheses do not apply to current processing technology where no pre-twist is involved.

Some attempts have been made to improve the understanding of the events that occur during the texturing of no-twist yarns by modern texturing nozzles. Bock and Luenenschloss²⁵⁻²⁷ analysed the mechanism of texturing by using a Taslan Type 14 nozzle. Their research confirmed the findings of Sen²¹ and Sivakumar²² by verifying the occurrence of the shock waves in the free jet from this nozzle by means of Schlieren photography. They also gave evidence of asymmetry in the flow, which they verified by pressure measurements, as expected from the asymmetric design of the nozzle. By using high-speed photography, they showed that the filaments were opened on emergence from the nozzle. Like Wray¹⁶ and Sen²¹, they showed that the velocity gradients and the turbulence within the stream helped the texturing by altering the forces acting on individual filaments, which in turn caused longitudinal displacement of the filaments relative to each other. However, they argued that there is a force within the stream that causes the filaments to change their directions and stated: 'otherwise bending of the filaments would not have been possible'. They concluded that this bending force was due to a 'pressure barrier' caused by the shock waves. They summarized the loop-formation mechanism as follows²⁶:

'The filament yarn is opened in the nozzle by turbulence and/or gradients of the flow velocity, and places itself in a stream of high kinetic energy below the nozzle axis. With a right-angled draw-off after the nozzle, an interlacing point forms above the axis, at the interface between two zones of different flow states. The filaments blown through below this interlacing point pass through a zone of high air

turbulence, and are decelerated by the subsequent drop of the dynamic pressure. When the filaments interlace, loops projecting from the yarn are formed by the differently sized filament bends'.

The Bock and Luenenschloss hypothesis of loop formation was also based on the 'retardation' or 'deceleration' of the filaments by the variations in the pressure as a result of the shock waves, as Sivakumar²² claimed in 1975. The validity of texturing mechanisms attributed to the presence of shock waves is questioned in Part II²⁸ and Part III²⁹ of this series of papers as a consequence of flow visualizations and high-speed-photography experiments.

MISCELLANEOUS OTHER WORK

Although they did not analyse the mechanism of loop formation, other workers, such as Kollu³⁰, Artunc^{31,32}, Piller^{13,33,34}, Hes and Piller³⁵, Bock and Luenenschloss³⁶, Rozmarinoska and Godek³⁷, and Dtye and Bose³⁸, all investigated either various aspects of textured-yarn properties or the effect of various parameters on the properties of textured yarns.

Wilson³⁹ gives a useful review of the process together with a list of references and patents published up to 1977. There are also many minor publications relating to the end-uses, economic factors, and future potential of air-jet textured yarns, as well as other patents, but they are too numerous to mention here.

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