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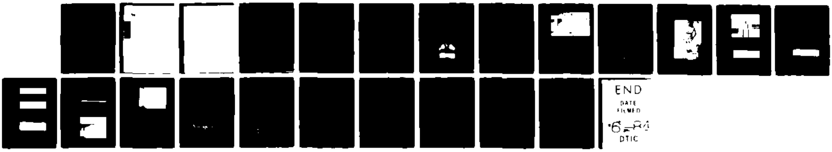

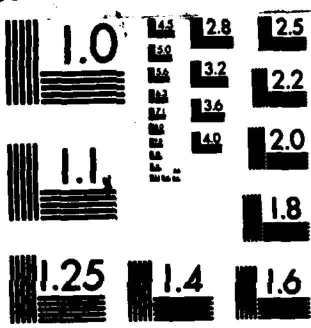

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ABSTRACT

A program was conducted to assess the feasibility of "Roll-Truding" (RT*) fiber-reinforced composite structures. The primary objective of this effort was to develop a processing method for continuous profiles of fiber-reinforced/epoxy matrix composites that could significantly increase production rates obtainable by pultrusion.

The concept of "Roll-Trusion" (RT*) or pull-forming centers on the use of pf heated rollers was to (1) feed the stock material, (2) form the profile shape, and (3) provide the heat required for curing of the thermosetting resin.

A bench model "Roll-Truder" (RT*) apparatus was constructed; 1-inch wide glass/epoxy and graphite/epoxy specimens were successfully produced.

CONTENTS

Page

INTRODUCTION

Numerous applications exist in today's Army for lightweight load-bearing structures. Many of these applications are now based on pultruded glass fiber/polyester composites that are produced in a variety of configurations on commercially available equipment at rates exceeding 9 feet per minute (fpm). However, for many other applications it is desirable to use an epoxy/resin formulation as the matrix to improve strength and environmental properties. Pultruded glass fiber/epoxy composite structures can be manufactured but only at an uneconomical speed of 6 to 8 inches per minute (ipm), a commercially unfeasible rate for most end-use applications. Drag, resulting from lower shrinkage and slower epoxy cure rates, resulted in longer contact time in the die body.

To compensate for this excessive drag and unacceptable production rates, a unique manufacturing technology, "Roll-Trusion" (RT*) or pull-forming, has been developed for commercial rate manufacturing of a variety of functional shapes. The inherent versatility of this process is complemented by the attractive production rates that are achieved via incorporated moving surfaces that provide the feeding, forming, and curing functions.

In the "Roll-Truding" (RT*) process, a continuous fiber reinforcement is passed through an A-stage resin bath to coat the fibers. These wetted fibers are then passed through one or more sets of heated rolls to form the fiber mass into the desired cross-section and to initiate resin curing. The internally heated rolls may be ground to the shape of the desired profile or "die sides" may be used. Figure 1 shows the die sides that were used in this investigation. Figure 2 shows how the same effect could have been achieved using ground rolls.

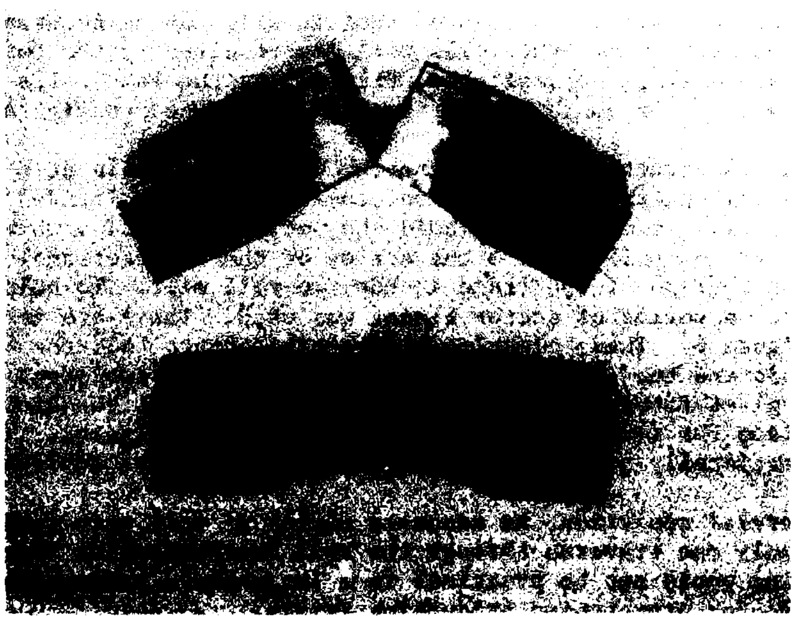

Figure 1. Two-piece die sides.

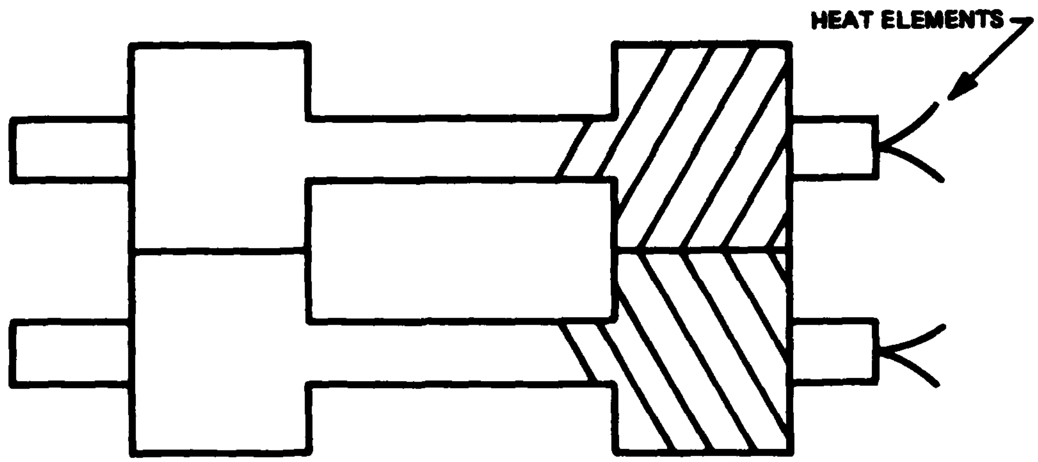

Figure 2. Ground metal rollers.

SYSTEM DESCRIPTION

In this investigation a two-roll, variable/non-differential speed compounding mill was modified to demonstrate the feasibility of the "Roll-Trusion" (RT*) concept. The two-roll mill could be positioned either horizontally or vertically as shown in Figure 3. In this vertical position the mill had all of the characteristics of one of the roll sets that would be available on production-scale equipment. Figure 4 illustrates the schematic setup for this production system.

On a production scale it is assumed that it will not be necessary to incorporate separate "pullers" since the rolls will impart directly the forward thrust to the profile. This will be accomplished primarily by the last rolls in the series since this set will be in contact with the cured, hardened configuration.

A frame was constructed to transport the wet fiber bundle at a constant speed on the experimental equipment. The frame, constructed of pultruded glass fiber/polyester bar stock, was designed to hold the wet fiber bundle, while the entire apparatus moved horizontally due to the action of the bidirectional motorized rolls. Figure 5 is a photograph of the frame in the two-roll mill. To help clean the rolls during operation, a series of doctor blades was used. These are seen clamped to the die sides in Figure 6. These cleaning blades also act to hold the die sides together, helping to define the dimensions of the profile. The two steel parallels on the outside of the glass fiber/epoxy bundle rest snugly against the die sides. Care was taken not to clamp the rolls too tightly to prevent roll binding. The rolls were then run bidirectionally at the desired speed until cure was achieved.

In a commercial operation, an adequate number of roll sets would be used for curing during only one traverse through the roll heating/curing system. Dual direction feeding would not be practical in a large-scale production operation albeit tolerable for prototyping production trials.

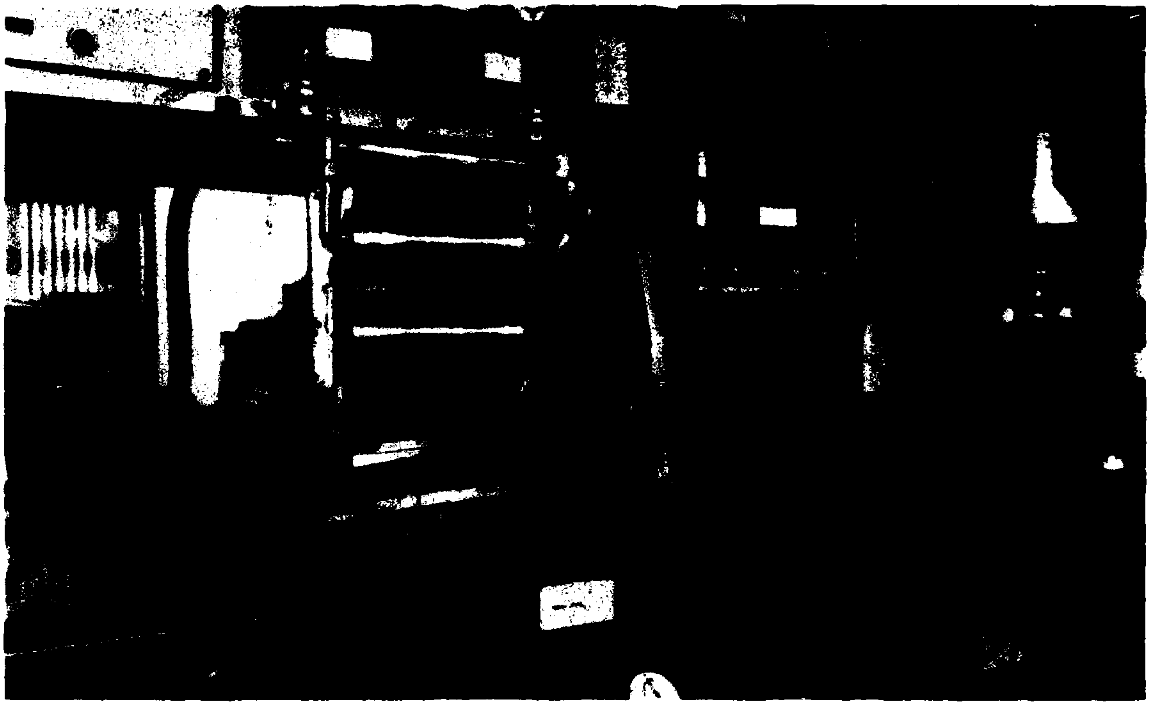

Figure 3. Two-roll mill without sides in place.

OPERATING PROCEDURE

The experimental apparatus was assembled as depicted in Figure 5. In this photograph the rolls were positioned at the greatest gap separation possible. The wetted fiber bundle was passed through the rolls and clamped in the frame. The frame was positioned at the bottom of its stroke, with the majority of the frame behind the rolls. A strip of Aramalon* was placed around the bundle between the rolls to prevent resin migration-dripping and curing onto the rolls. The desired roll temperature was set. At operating conditions, a coating of silicone release agent was applied, the rolls were closed, and the entire frame was centered on the rolls.

MATERIAL PROCESSED

The initial materials evaluated were Great Lake's CG-5 graphite fiber and A-staged Shell's Epon* 826 350°F anhydride cured epoxy resin. The large fiber bundle was separated into small bundles approximating the ultimate volume of the desired profile.

The first composite formulation was charged in the "Roll-Truder" (RT*) as outlined in OPERATING PROCEDURE. The roll temperature was set at 325°F to offset the short residence time between the rolls moving bidirectionally at 10 rpm (10.68 fpm). The part cured to a hard 0.25 x 1.0" profile in approximately 10 minutes and is shown in Figure 7. The distorted final shape is due to insufficient clamping

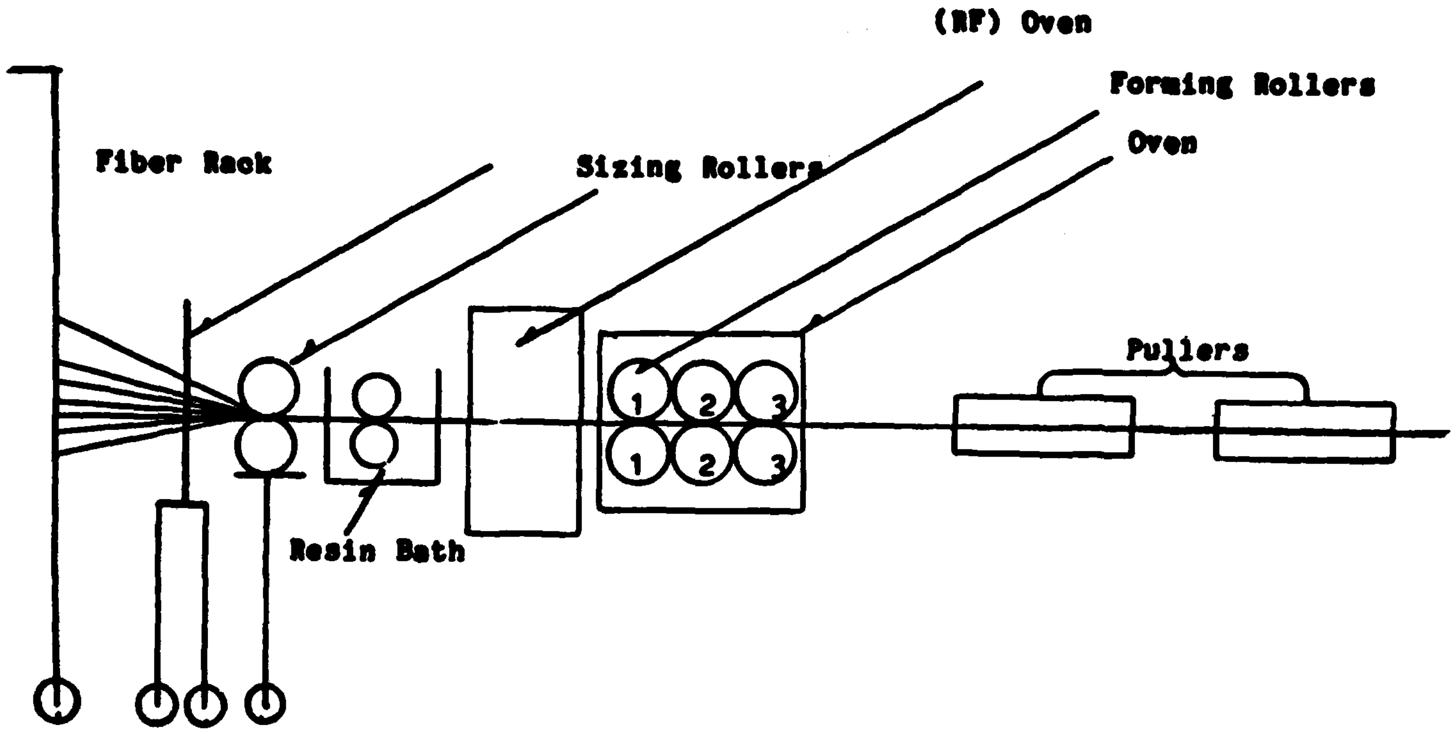

Figure 4. Schematic setup of production system.

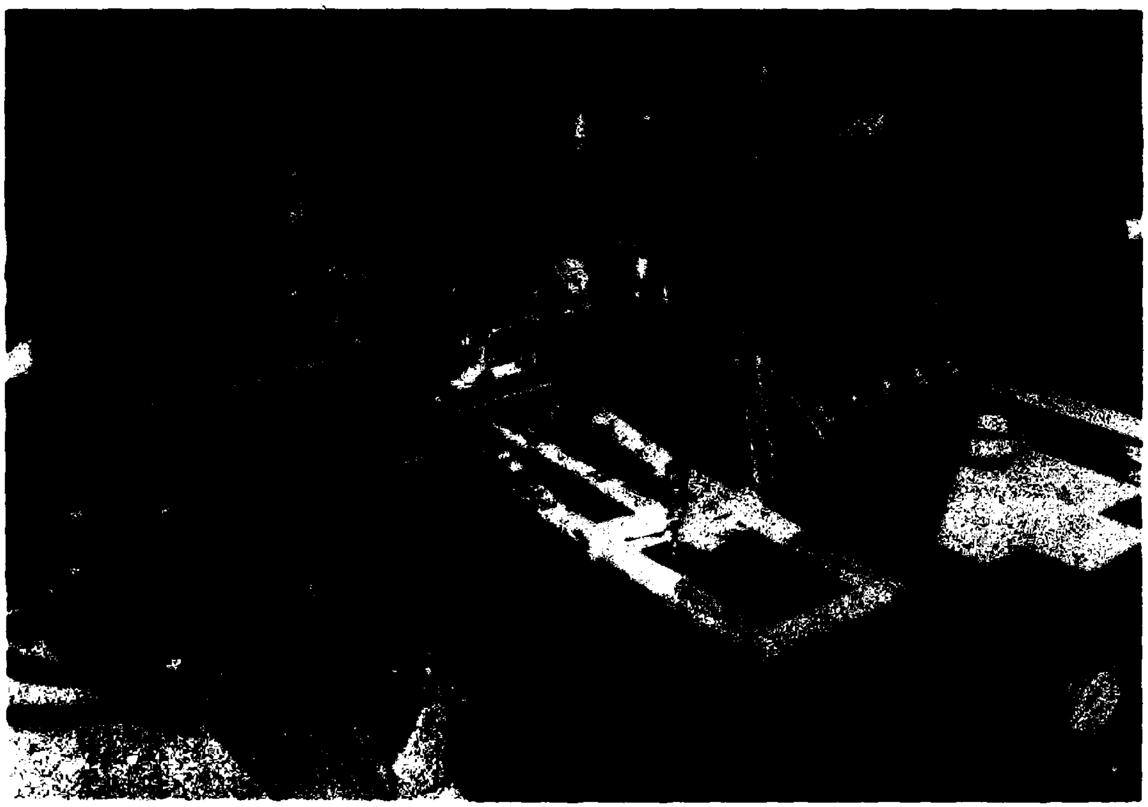

Figure 5. Two-roll mill with frame in place.

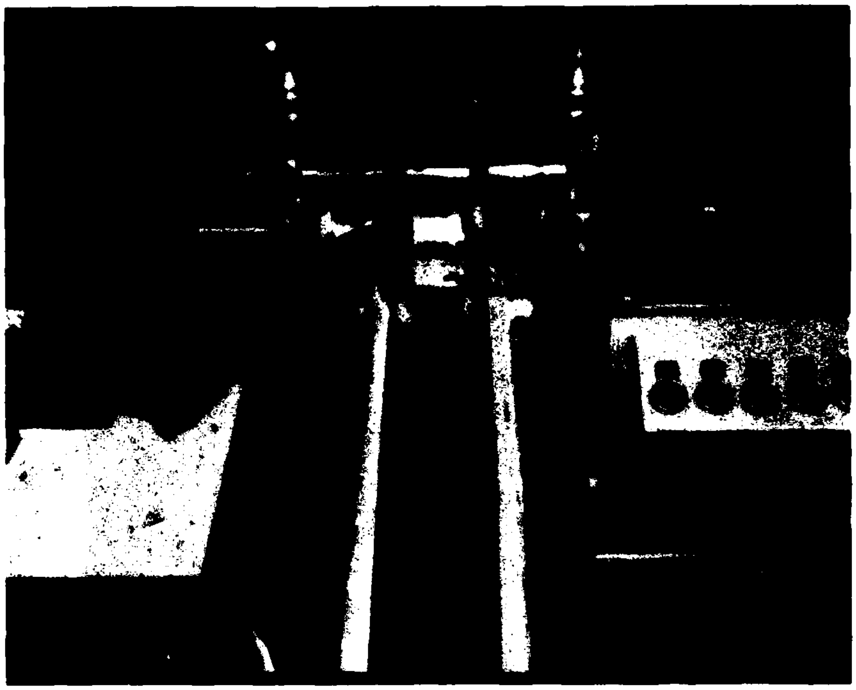

Figure 6. Doctor blade placement on two-roll mill.

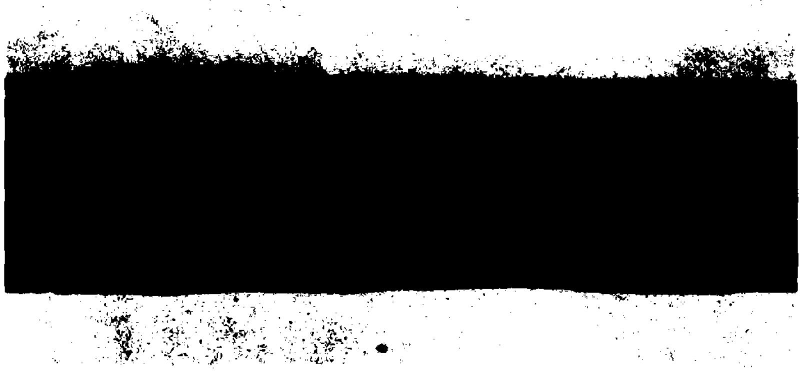

Figure 7. Graphite/epoxy roll-truded (RT®) part. Part 1.

tension. The profile also exhibited numerous crossovers due to the separating procedure necessary to obtain small bundles from the pultruded waste bundle.

The second bundle was processed similarly using a roll temperature of 385°F to reduce the cure time to 7 minutes. This fabricated part is shown in Figure 8. The stock was discolored from overheating and misshapened due to the adhesion of the fibers to the roll.

The third formulation, an S-2 glass fiber/epoxy 250°F cure prepreg, was formed at 350°F roll temperature at 5 rpm (5.34 fpm). This extreme temperature produced imperfect profiles as shown in Figure 9.

The fourth profile, based on a 350°F cure graphite/epoxy prepreg, was cured at 400°F roll temperature at 5-rpm roll speeds. The product exhibited good surface quality and dimensional control and is shown in Figures 10 and 11.

Also evaluated was a 250°F cure 3M's SP-250 glass fiber/epoxy prepreg that was processed at 335°F and at 5 rpm. This profile exhibited excellent dimensional stability and surface appearance/smoothness. This "Roll-Truded" (RT*) profile, shown in Figures 12 and 13, was physically indistinguishable from conventional pultruded stock.

Figure 8. Graphite/epoxy roll-truded (RT*) part. Part 2.

Figure 9. Glass fiber/epoxy part. Part 3.

Figure 10. Graphite/epoxy prepreg part. Part 4.

Figure 11. Overview. Part 4.

Figure 12. Glass fiber/epoxy prepreg. Part 5.

Figure 13. Overview. Part 5.

OBSERVATIONS AND CONCLUSIONS

The following observations and conclusions were determined:

1. "Roll-Trusion" (RT*) efficiently cures FRP (glass or graphite/epoxy profiles) in 0.25-in. thick sections.

2. The morphology of the cured profile was comparable to an identical pultruded part.

3. The mechanical properties were predicted to be similar to pultruded parts at equivalent fiber volume loadings.

4. There was no apparent die drag associated with the "Roll-Trusion" (RT*) process.

5. Low cost "composite rollers" would afford significant economic savings in tooling costs (Figure 14).

6. An automated gantry roller mechanism appears to be a viable approach for in-line changes of shapes for production of profiles with cross-sectional variations (Figure 15).

7. Cross-sectional variations can be easily made by changing the fiber content.

8. Cross-sectional variations can be easily accomplished by two-axis operation of a roller assembly (Figure 16). Examples of sample structural shapes are shown in Figure 17.

9. The "Roll-Trusion" (RT*) technology can be extrapolated for processing a second generation of engineering thermoplastics and sheet molding compound.

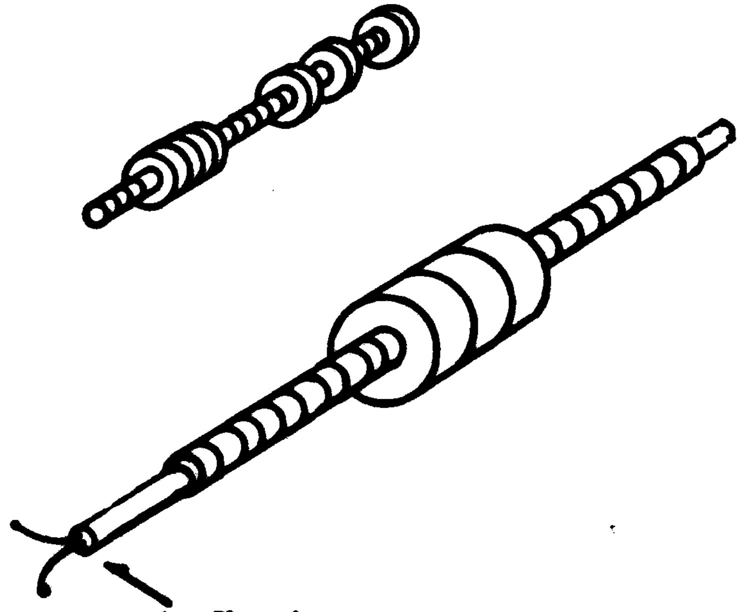

Figure 14. Forming rollers.

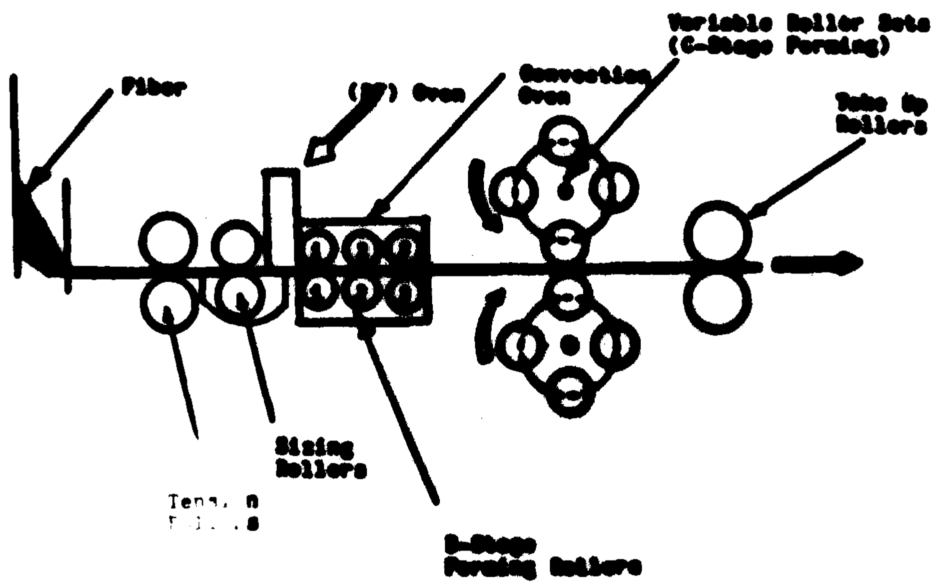

Figure 15. Automated production by rollers, variable section concept.

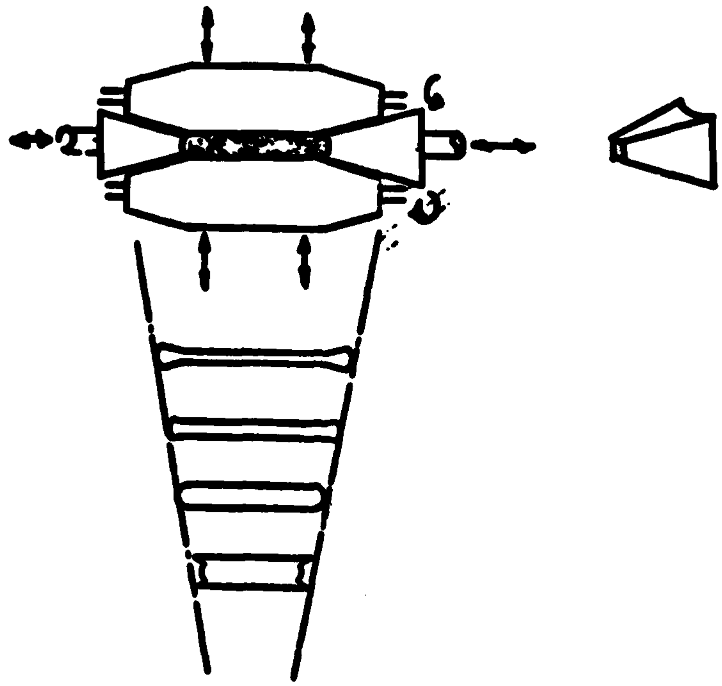

Figure 16. Variable cross-section, two-axis concept.

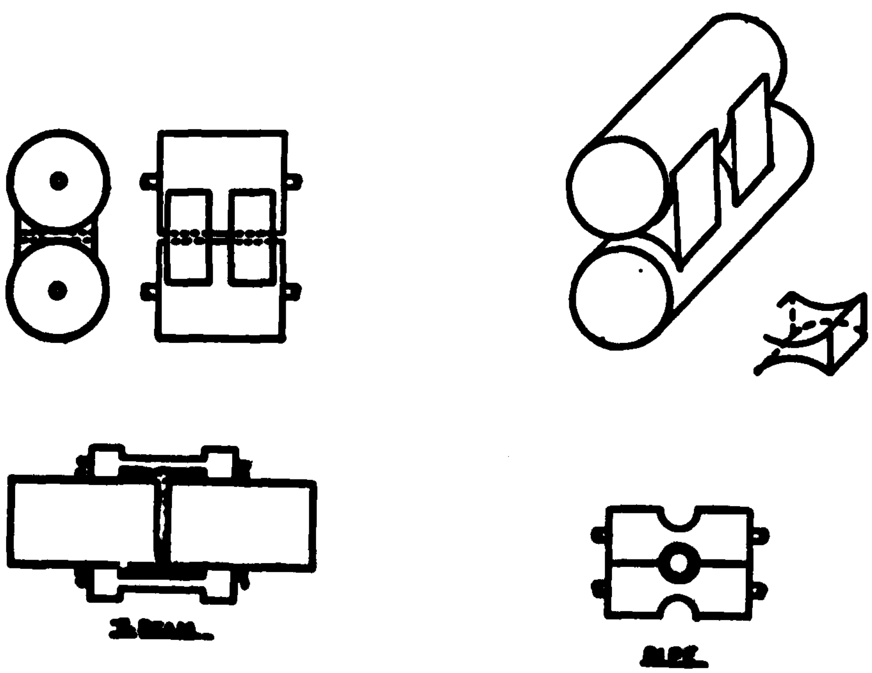

Figure 17. Profile dies.

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