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Thermoplastic Pultrusion Process using Commingled Glass/Polypropylene Roving

By

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Abstract

This paper discusses the development of a novel thermoplastic pultrusion process utilizing commingled glass/polypropylene fiber roving. The development of a commercially viable thermoplastic pultrusion process resulted in combining technologies, tooling and processing techniques from both pultrusion and extrusion manufacturing processes.

The process was capable of producing unidirectional and transverse reinforced profiles ranging from small diameter rods up to 5" x 5" thick walled tubing profiles.

Capstock extrusion capability was also added to allow great flexibility in easily adding beneficial attributes to the underlying composite profile.

First commercial applications included the development of unidirectional pultrusions for the fence and tool handle market. Additional development also produced transverse reinforced profiles, twisted profiles as well as unique capstock extrusion effects.

The result is a thermoplastic pultrusion process which opens the door to future advances utilizing other thermoplastic resins, reinforcement fibers and direct thermoplastic resin injection. Thermoplastic pultrusion also offers the possibility for pultrusion and extrusion manufacturers to expand into new product and market segments not otherwise open and available to them currently.

Challenges of Thermoplastic Pultrusion

The notion of thermoplastic pultrusion is not novel, with first published work going back to 1985. (1)(2) However the ability to commercialize production of lower cost, high volume applications has faced several challenges and obstacles for the processor.

In contrast to pultrusion resin formulation viscosities that typically range from 100 to 5,000 CPS, thermoplastic resins such as Polypropylene, PVC, Polyethylene and others exhibit relatively high melt viscosities of up to 500,000 CPS in comparison.(2) In addition, thermoplastic resins only exhibit their reduced viscosities at elevated temperatures, presenting challenges to resin delivery and wetout using traditional pultrusion processing techniques.

Increased viscosities have a direct effect on a pultruder's ability to efficiently and properly achieve fiber wetout. (3) A general relationship for defining wetout was proposed in 1984 as follows:

$$\text{Wetout} \propto \frac{T_a\, w\, t}{u}$$

Where T_a = resin temperature when applied to fiber, w = work applied to fibers, t = immersion time, and u = resin viscosity. (3)

As seen in this general relationship, as resin viscosity increases, under the same conditions, the ability to properly wetout fibers decreases. Not only does viscosity affect a processor's ability to maximize the resin & fiber interface, it is also an important variable on the permeability of the resin through a profile's fiber matrix during wetout, profile forming and ultimate consolidation.

Since the melt viscosities of thermoplastics resins are significantly higher, published experimental work on thermoplastic wetout of fibers has primarily focused on the methods and techniques to maximize the work (w) component of this general wetout relationship.

Thermoplastic techniques to improve this work component (w) generally consist of either applying increased pressures or mechanical methods to increase fiber wetout by the thermoplastic resin.

A number of published articles speak on the use of heated wetout pins to improve melt flow along fibers and reduce void content of commingled glaaa/polypropylene fibers (4)(5)

Another challenge is to also account for the differences in the elevated temperature behavior of a thermoplastic composite versus that of traditional thermoset pultrusions during processing. At elevated processing temperatures, thermoplastic composites are much more fluid in their behavior and the control of profile temperature during processing is more significant in forming a finished profile to exacting dimensions.

An additional challenge in tooling and process design was to also account for the viscoelastic characteristics of thermoplastics resins to exhibit die swell and expansion during processing.(6)(8) Figure 1 – depicting model of die swell behavior of tubular extruded profile.

Utilizing a Commingled Roving

The initial use and selection a commingled glass/polypropylene (Glass/PP) fiber roving was chosen primarily to reduce overall development time and seen as a first step towards future developments of direct thermoplastic resin injection.

The Twintex®, Glass PolyPro Roving is a roving product that is a commingled yarn of glass fibers combined with polypropylene fibers. Production of a commingled fiber product involves the addition of a multi-filament extrusion process to the glass manufacturing process. See Figure 3 depicting the manufacturing process used to make commingled glass/polypropylene roving. This extrusion process is commonly used in the production of carpet yarns.

The use of Twintex, Glass PolyPro Roving was chosen for several reasons:

- Commingled glass allowed thermoplastic resin to be predistributed throughout the fiber matrix.
- Set glass fiber concentrations of 60% and 75% (by wt.)
- Polypropylene resin of mid range melt flow index (MFI)
- Reduced preliminary cost and development time of adding additional in-situ extrusion resin deliver equipment to processing line.
- Provided in a roving package that product manufacturing staff was experienced in handling.
- Ability to easily and accurately adjust range of fiber content by altering ratio of 60% and 75% rovings used in profile.
- Available in high quantities.
- Proven product history and processing knowledge from other composite processes utilizing product.

These benefits did, however; come at a premium to the final product cost. Raw material cost analysis of glass fiber and polypropylene does demonstrate that commingled fiber comes at a significant cost premium to the processor. Significant cost saving opportunities are shown to exist with future process advancements utilizing direct extrusion resin impregnation techniques.

Driven by Heat, not by Reaction Limitations

Unlike traditional thermoset pultrusion, in which speeds are typically driven by the limits of resin polymerization kinetics, the thermoplastic pultrusion process is not limited on such factors. [7]

Three dominant factors influencing product speeds and quality are heat energy input, tooling design and part cooling consolidation.

As with thermoplastic extrusion, line speed is directly related to the process line's ability to quickly and efficiently heat up the thermoplastic resin to melt temperature, have sufficient work be applied to create adequate wetout and to efficiently remove heat while consolidating and setting the part to final part dimensions.

Utilizing both Pultrusion and Extrusion Techniques to Build a Line

Unlike thermoset pultrusion lines which use typical die lengths of 36"-48", tooling was altered to take into account the processing characteristics of thermoplastics.

Processing commingled glass/polypropylene fibers through traditional tooling setups, fails to account for the differences of pultruding two vastly different resin families. For a thermoset pultruder to process most thermoplastic resins in the same manner as thermoset resins would most likely not lend itself to the to a process of commercial viability for most thermoplastics.

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To account for the material differences, principles from extrusion tooling, die and calibration equipment were adapted and utilized to accommodate the thermoplastic pultrusion process. Borrowed extrusion technologies incorporated the adoption of chilled water calibration systems and segmented tooling.

Calibration techniques and tooling are well established processing steps for the extrusion process. Calibration of profiles allows for removal of heat in a controlled fashion while tooling assists to properly size and calibrate the finished product during processing. See Figure 1A showing a view of a typical calibration system used in the manufacturing of extruded PVC window profiles. See Figures 4, 4A and 4B depicting several configurations of calibration techniques used in extrusion processing.

The Thermoplastic Pultrusion Process

The thermoplastic pultrusion process developed utilizing the commingled glass/polypropylene roving consists of the following sections:

- Fiber/reinforcement storage area
- Fiber Preheating*
- Thermoplastic Melt and Fiber Wetout
- Profile Forming & Consolidation
- Composite Calibration Tooling
- Capstock Extrusion*
- Capstock Embossing/Knurling*
- Final Cooling and Calibration
- Cutoff Saw

*denotes optional sections depending on finished part requirements

Line Diagram - See Figure 2 depicting line layout of the developed thermoplastic pultrusion line.

Initial Commercial Applications

First commercial product applications consisted of products for the ornamental fencing market and existing tool handle market.

Five ornamental fence profiles were produced that ranged from a ¾" square tubing picket profile, up to a 5" x 5" square tubing post profile. See Figure 5 showing product fence profiles. This product line was designed as a composite fence product that competed against existing wrought iron and aluminum ornamental fencing products in the commercial segment.

Extrusion capstocking allowed a high aesthetic surface to be applied to the underlying composite profile. Also the capstock was a highly UV resistant resin capable of meeting the extreme weathering demands of fencing products. Using a compatible capstock can also take advantage of residual profile heat to promote adhesion between the composite and capstock layer.

The added capstocking capability can relieve the demands on processors in adding resin additives to the composite matrix for certain characteristics such as UV resistance, surface finish or color.

The second commercial application consisted of innovative tool handle designs that took advantage of the lines capstocking capabilities. See Figures 6, 7, 8, 9 showing capstocking and special effect that can be applied to the capstock layer.

Capstocking also allowed resins of two different types, colors and/or durometers to be applied longitudinally during processing, adding new design options for tool handle manufacturers. See Figure 7 depicting capstocking of profile with two differing colors and durometer materials.

Profiles incorporating transverse fiber reinforcement was also performed utilizing existing glass/polypropylene woven sheet material. See figure 10 showing channel profile produced using transverse woven glass/polypropylene sheet material on outer layers.

Why Thermoplastic Pultrusion?

Earlier papers regarding benefits that thermoplastics pultrusions offer are discussed as offering the following benefits (7):

- Increased impact resistance
- Increased toughness
- Thermal and ultrasonic part welding – See Figures 11, 12 showing thermal welding used to join two fence tube profiles and cutaway of ultrasonically welded ID plug in round tool handle profile.

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- Limited post forming capabilities – Figure 13 showing limited circular twisting of fence tube profiles.
- High line speeds
- Minimal to no volatile emissions during processing
- Better recyclability opportunities
- New design and market opportunities
- Potential cost savings
- Selective extrusion profile reinforcement offers new product opportunities. – Figures 14, 15 depicting concept of selective reinforcement of extruded profiles using small diameter thermoplastic pultruded rods.

New Market Opportunities

The development of a thermoplastic pultrusion process opens up new possibilities for product design. From a completely reinforced profile down to an extruded profile reinforced with strategically placed fibers, a new broad spectrum of physical performance is opened up for product designers.

Strategic reinforcement

Selectively reinforcing PVC fence, window and decking profiles offer the opportunity to significantly improve flexural modulus of existing profiles. This affords extruders opportunities to reduce or eliminate aluminum stiffeners and to increase part spans. A broader range of material properties can be offered to final customers and product designers. See Figures 14, 15 depicting concept of selective reinforcement of extruded profiles using small diameter thermoplastic pultruded rods.

Reduced fabrication costs

Corner welding can reduce or eliminate gusset costs. Welding offers opportunity to join parts and/or eliminate adhesive operations. See Figures 11, 12 showing thermal welding used to join two fence tube profiles and cutaway of ultrasonically welded ID plug in round tool handle profile.

New Design Options

Profile twisting, capstock features and added extrusion capabilities bring new level of features and improved cosmetics for designers to incorporate. Figure 13

Future Development Opportunities

Future developments involve improvements in wetout and part consolidation to optimize composite mechanical properties.

Initial line developments yielded the underlying composite reaching 80-85% of theoretical strengths. These lower than expected values were mainly attributed to first generation calibration tooling system that was utilized.

Refinement in calibration tooling and cooling offer opportunities to achieve higher line speeds, improve product quality, narrow part tolerances and achieve higher theoretical strength values.

The addition of a future in-situ resin extrusion injection system also creates an alternative to using commingled fiber rovings and open opportunities for cost reduction and additional thermoplastic resin options.

Conclusion:

A commercially viable thermoplastic pultrusion process has been developed using commingled glass/polypropylene roving that offers many new product opportunities.

The process utilized processing and tooling techniques from both standard extrusion and pultrusion processes. The created thermoplastic pultrusion line was a hybrid of these technologies capable of adequately wetting out glass fibers while also accommodating the nature of the thermoplastic resin in the final profile formation.

Such a process opens up new possibilities in new products based on families of thermoplastic resins being manufactured into pultruded composites.

These new possibilities are not only limited to existing pultrusion markets and application but can also serve the opportunity to expand traditional extrusion markets by increasing performance with the addition of continuous fibers reinforcements.

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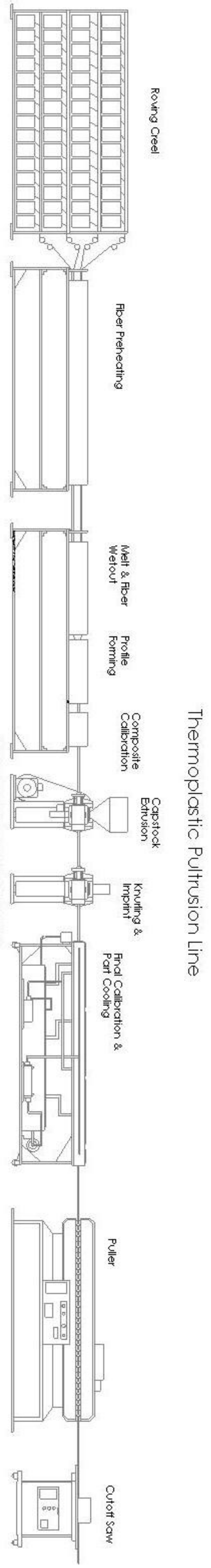

Figure 2: Thermoplastic Pultrusion Line Diagram

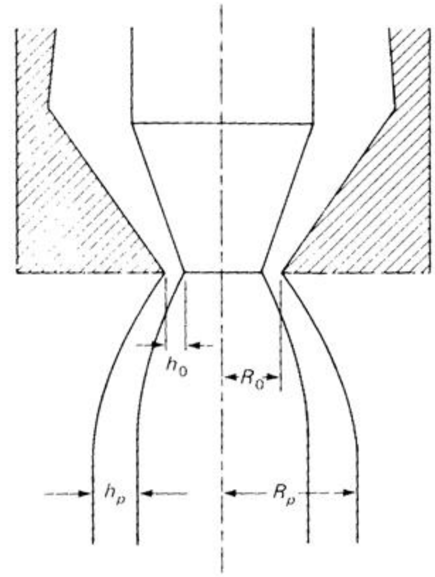

Figure 1: Die Swell behavior of extruded tubular profile. (6) p. 473

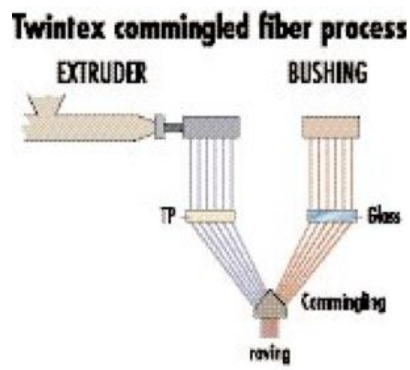

Figure 3: Commingled glass/polypropylene fiber manufacturing process.

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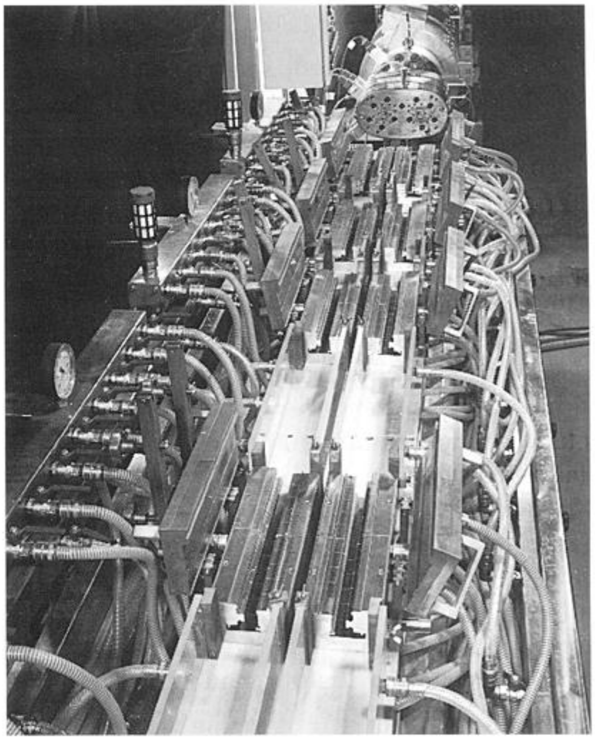

Figure 4 Twin orifice die and vacuum block calibrator used in window profile extrusion (8) p 89

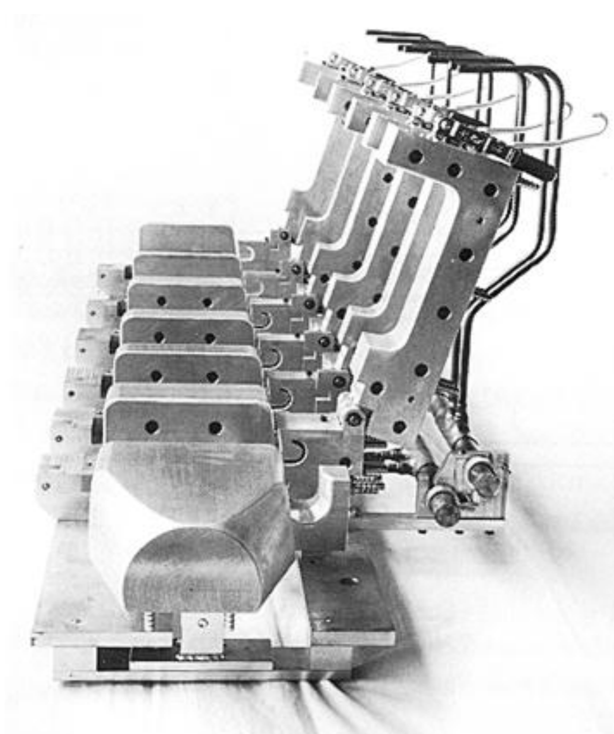

Figure 4A Extrusion segmented or template calibration (8) p. 91

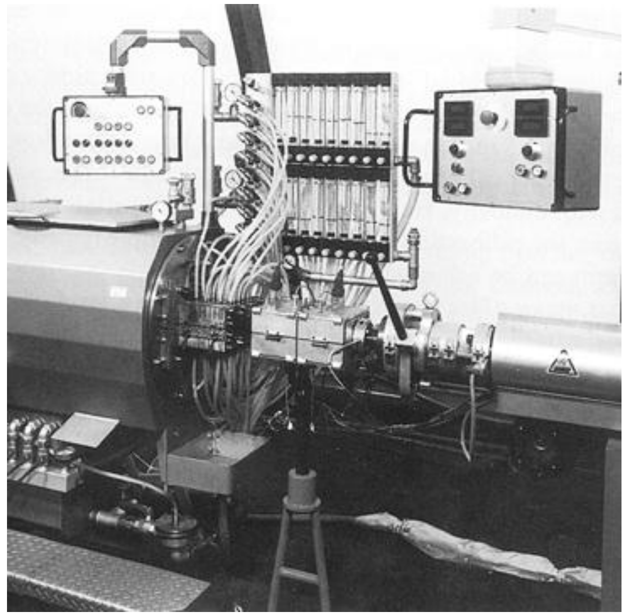

Figure 4B Vacuum tank with short vacuum calibration unit for profile and pipe production (8) p. 94

Machine Design
http://machinedesign.com/article/long-glass-fiber-pp-hits-the-road-1024
Accessed Sept 25, 2010

Figure 5: Thermoplastic Pultrusion Fence System

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Figure 6: Thermoplastic Pultrusion Tool Handles

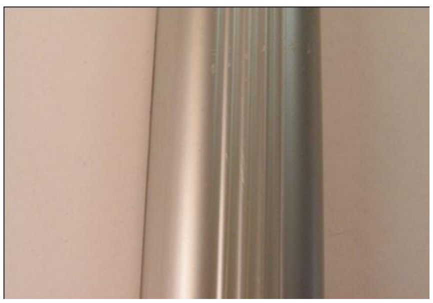

Figure 7: Thermoplastic Pultrusion Tool Handles – Inline Capstocking Detail

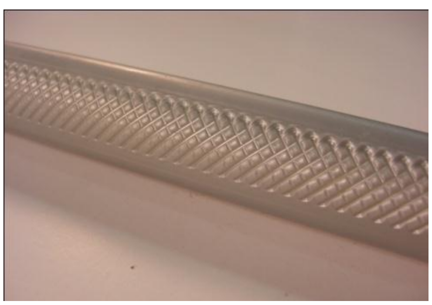

Figure 8: Thermoplastic Pultrusion Tool Handles – Inline Capstock Knurling

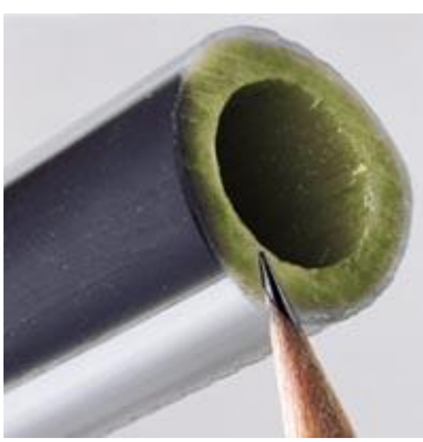

Figure 9: Dual Capstocking of Thermoplastic Pultrusion (Courtesy Polygon Company)

Figure 10: Transverse Fiber Thermoplastic Pultrusion Channel profile – no capstock

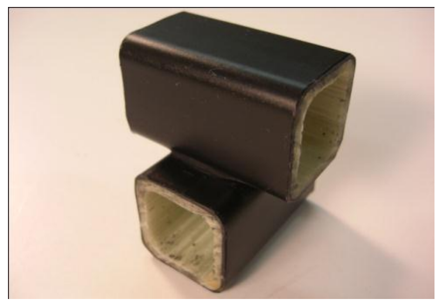

Figure 11: Thermal Part Welding of Thermoplastic Pultrusion

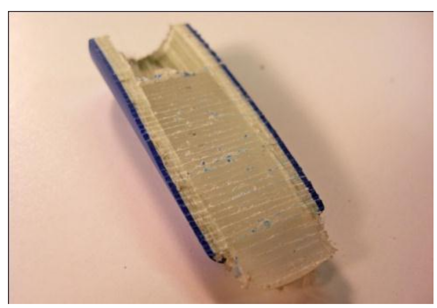

Figure 12: Spin Welding of End Plug into Thermoplastic Pultrusion Tool Handle

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Figure 13: Post Forming of Thermoplastic Pultrusion - Twisting

Figure 14: Selective Reinforcement of recycled deck profile using Thermoplastic Pultrusions

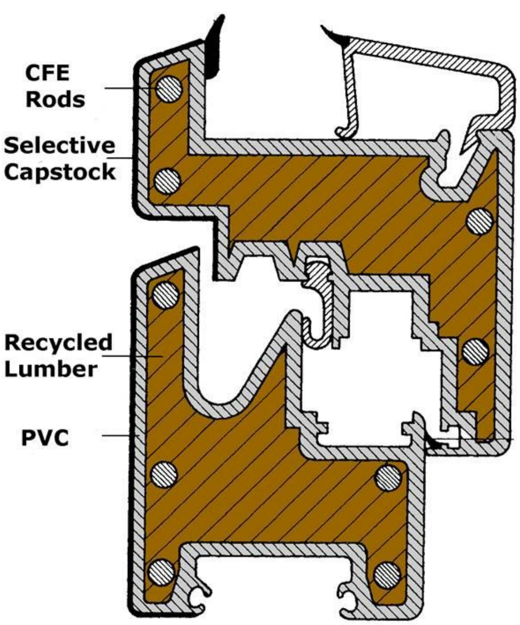

Figure 15: Selective Reinforcement Concept (5)

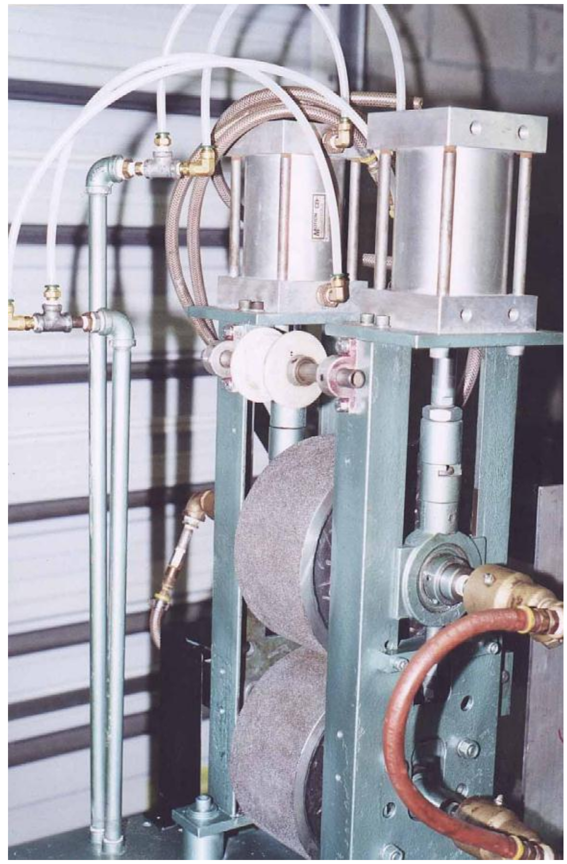

Figure 16: Capstock Embossing Equipment

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