RECENT DEVELOPMENTS IN PVC-C COMPOUND TECHNOLOGY

John Schroeder, Mark Julius and Henry Forsyth
Noveon, Inc.
Brecksville, Ohio, USA

Chlorinated polyvinyl chloride (PVC-C) plastic piping is often used where elevated temperature performance and excellent chemical resistance is needed. However, compared to some other plastic materials, PVC-C can be more difficult to process and generally restricted in size to smaller dimension pipe. The commercial acceptance of PVC-C piping has thus been somewhat limited, especially for industrial applications where more demanding performance and larger pipe sizes are required. As a result, two new industrial PVC-C pipe compounds have recently been developed. One product is a new ultrahigh impact strength material that has been shown to exhibit more than 5 times the toughness of most other PVC-C products. The other product is a new large diameter pipe extrusion compound that allows for production of pipe sizes beyond 12" SCH80 (325x17 mm). In addition, recent technological efforts have also led to the development of a pressure rated PVC-C fitting compound that has the same design stress as PVC-C pipe. The development and attributes of each of these new products are discussed.

High Impact Strength Pipe

Impact strength and ductility are of critical importance to the overall performance of a piping system. A high level of impact strength is often necessary to insure that a pipe is capable of withstanding the many abuses that can occur from the time when a pipe has been produced to after it is installed. Many times damage can occur either during shipment, when the pipe is installed, or even during normal operations. This problem becomes even more pronounced particularly when the pipe is subjected to sub-ambient conditions. Since damage to the pipe is not always apparent, damaged pipe is sometimes installed and operated for months or even years later before it eventually fails. Therefore, pipes that do not have good toughness and ductility are more prone to damage and failure in the field.

Pipes having good impact strength are dependent upon two principle factors. First, and foremost, is the inherent impact strength of the material. This property is governed by such variables as resin molecular weight, as well as the type and level of various additives. Generally speaking, the use of a higher molecular weight resin and impact modifiers tends to improve impact resistance, while pigments and fillers are often detrimental. However, proper design of a material is often a fine balance between a several desired properties. For example, increasing the impact strength of a material typically results in a corresponding reduction in the materials' tensile strength, modulus, and flow.

The second factor affecting impact strength and ductility of pipe is that of processing. Not only does the material need to have good impact strength, but it must also be properly processed. Properly processed materials will result in a finished product with good impact resistance, while the same material if processed incorrectly will often result in poor impact resistance. Unfortunately, proper processing of a poorly designed material will not result in same level of impact strength and ductility as a material with good inherent impact resistance.

Development of a new higher impact strength PVC-C pipe compound was conducted by first performing a Design of Experiment (DOE) study to determine the principle factors governing impact strength. To this end, a quarter fraction factorial (2^{6-2}), resolution IV, design with an added center point was utilized. This design allows all primary factors to be determined, however all interaction terms are confounded with each other and thus can not be independently isolated from this analysis. In addition, total experimental error was measured by replication of the center point. Compound constituents investigated in this study include processing aid, impact modifier, filler, and lubricant. The composition range for each of these additives was varied as widely as possible to determine its total effect. A total of 19 experiments were randomly prepared and evaluated as shown in Table I, where the representative term of “0” signifies a midpoint concentration, while the “+” and “-“ symbol signify a higher level concentration and a lower level concentration, respectively.

TABLE I
EXPERIMENTAL DESIGN

Sample No.	Processing Aid	Impact Modifier	Stabilizer	Filler	Lubricant A	Lubricant B
1	0	0	0	0	0	0
2	-	-	-	+	+	-
3	-	+	+	-	-	-
4	+	-	-	+	+	+
5	-	+	-	-	+	+
6	+	-	+	-	+	-
7	-	+	-	+	-	+
8	+	+	-	-	+	-
9	+	+	+	-	-	+
10	-	+	+	+	+	-
11	-	-	+	+	-	+
12	0	0	0	0	0	0
13	-	-	-	-	-	-
14	+	+	-	+	-	-
15	0	0	0	0	0	0
16	-	-	+	-	+	+
17	+	+	+	+	+	+
18	+	-	+	+	-	-
19	+	-	-	-	-	+

Samples were prepared by first blending all the ingredients in a Henschel mixer. The powder was then dropped into a cooling mixer until the temperature had reached approximately

110°C. Physical property specimens were then prepared by first mixing in a Farrel internal mixer with a set temperature of 175°C until the sample temperature reached ca. 210°C, after which the sample was then removed. The partially fused sample was then placed on a two-roll mill with a set temperature of ca. 205°C until a uniform sheet had been obtained. The material was then removed from the mill, cooled, and then compression molded into plaques from which test specimens were subsequently cut. In addition, each of the mixed powder samples were also extruded into ¾" SDR11 (22x2.0 mm) pipe using a CM55 counter-rotating twin screw extruder. The resulting pipe thus produced was then subsequently evaluated.

Analysis of the data is summarized in TABLE II. Linear statistical prediction models of the data indicate that the primary factor affecting impact strength, as measured by both Izod and falling dart impact strength on pipe, is the level of impact modifier. Analysis further indicates that the impact modifier level also has a negative effect on strength and modulus of the material without any significant affect on heat distortion temperature or stability. Similarly, increasing the level of the processing aid causes a decrease in both strength and modulus of the material, while increasing the level of stabilizer increases the stability of the material but also decreases the heat distortion temperature.

TABLE II
ANALYSIS OF RESULTS

Response	R^2	Error	Intercept	Process Aid	Impact Modifier	Stabilizer	Filler	Lub A	Lub B
STABILITY	78.8	2.520	14.30	0	0	3.9	0	2.3	1.25
HDT	96.4	0.553	107.4	-0.4	0	-2.81	0	0	0
IZOD	98.0	0.051	0.906	0.04	0.3044	-0.05	0.085	0.057	0
STRENGTH	97.3	66.75	8194	-165.0	-279.4	0	-110	-91.9	-57
MODULUS	88.6	6567	361210	-9875	-12750	3000	0	-5000	0
PIPE IMPACT	41.6	9.899	24.98	0	5.25	6.5	0	0	0

Table III is a simplified pictorial representation of the analysis showing the relationship between each constituent and the resulting physical properties. Units for each of the response variables are minutes, °C, ft-lbs/in, psi, psi, and ft-lbs, respectively. These findings thus indicate that in order to develop a PVC-C compound with increased impact resistance, primary efforts should be focused on optimization of the impact modifier.

The next question that then needs to be answered is which type of impact modifier would be best for toughness. Various types of impact modifiers are commercially available for vinyls, including acrylic, butadiene, olefinic, and chlorinated polyolefin. A second series of experiments was thus undertaken to determine which impact modifier would offer the best performance. This was accomplished by selecting a single formulation from which different modifiers were substituted and evaluated. The samples were prepared and tested according to the same procedures as described above.

TABLE III
SIMPLIFIED CONSTITUENT-PROERTY RELATIONSHIPS

	Processing Aid	Impact Modifier	Stabilizer	Filler	Lubricant A	Lubricant B
STABILITY	-	-	↗	-	↗	↗
HDT	-	-	↘	-	-	-
IZOD	-	↗	-	-	-	-
STRENGTH	↘	↘	-	↘	-	-
MODULUS	↘	↘	-	-	-	-
PIPE IMPACT	-	↗	-	-	-	-

Results indicate that that the various modifiers can be broadly categorized according to the classification scheme shown in TABLE IV.

TABLE IV
IMPACT MODIFIER PERFORMANCE

	Butadiene	Acrylic	Olefin	Chlorinated Polyolefin
ROOM TEMPERATURE	Excellent	Good	Good	Fair
LOW TEMPERATURE	Excellent	Poor	Fair	Poor

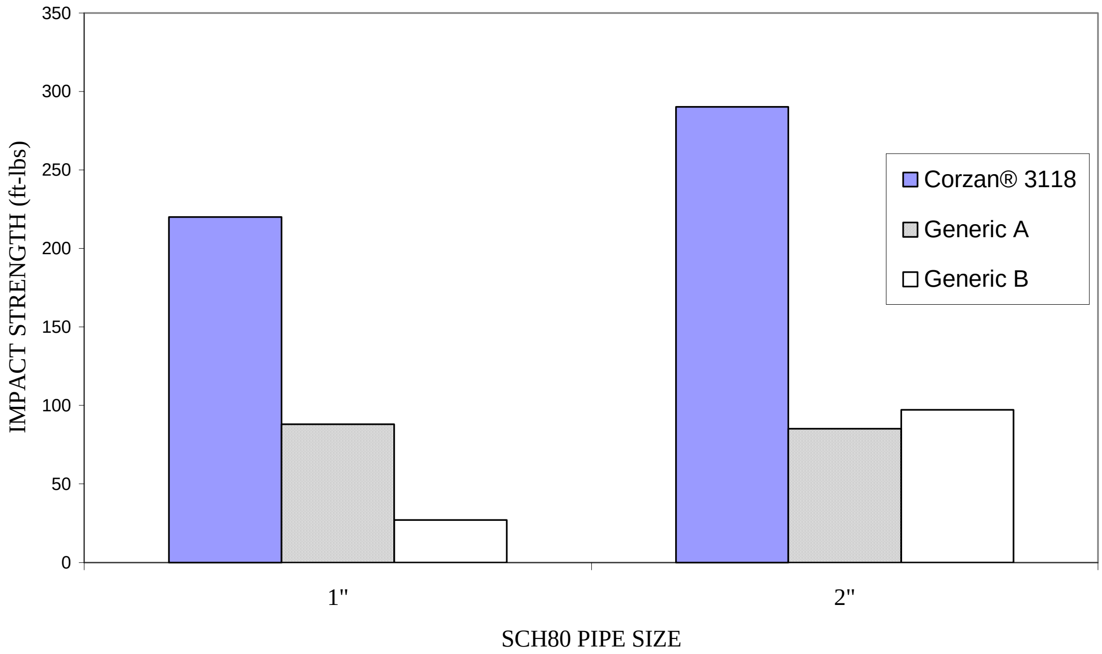
Based on information obtained from these two bodies of work a new high impact strength PVC-C pipe compound was developed and commercialized under the name of Corzan® 3118. A comparison of this product's basic physical properties to that of typical PVC-C product is given in Table V. Results indicate that this new material has more that 5 times the Izod impact strength compared to a typical PVC-C pipe compound.

TABLE V
BASIC PHYSICAL PROPERTIES

		Typical PVC-C	Corzan® 3118
Specific Gravity		1.54	1.51
HDT	^{o}C	115	115
Tensile Strength	Psi (MPa)	8,000 (55)	7,300 (50)
Tensile Modulus	Psi (MPa)	368,000 (2535)	360,000 (2480)
Flexural Strength	Psi (MPa)	13,600 (94)	13,200 (91)
Flexural Modulus	Psi (MPa)	389,000 (2680)	362,000 (2495)
Izod	Ft-lbs/in (KJ/m^2)	1.5 (7.8)	10 (52.4)
Rockwell Hardness	R Scale	119	119
NSF	14/61	Approved	Approved
ASTM	D1784	23447	24448

Corzan 3118 was subsequently extruded into different size pipes and evaluated by variable height falling dart impact testing at ambient temperature. Figure 1 shows that Corzan 3118 has more than 200 ft-lbs (270 J) of impact strength for pipe sizes equal to or greater than 1" SCH80 (33x4.5 mm) and a 2x fold improvement in toughness over that of other commercial materials.

FIGURE 1
Pipe Toughness

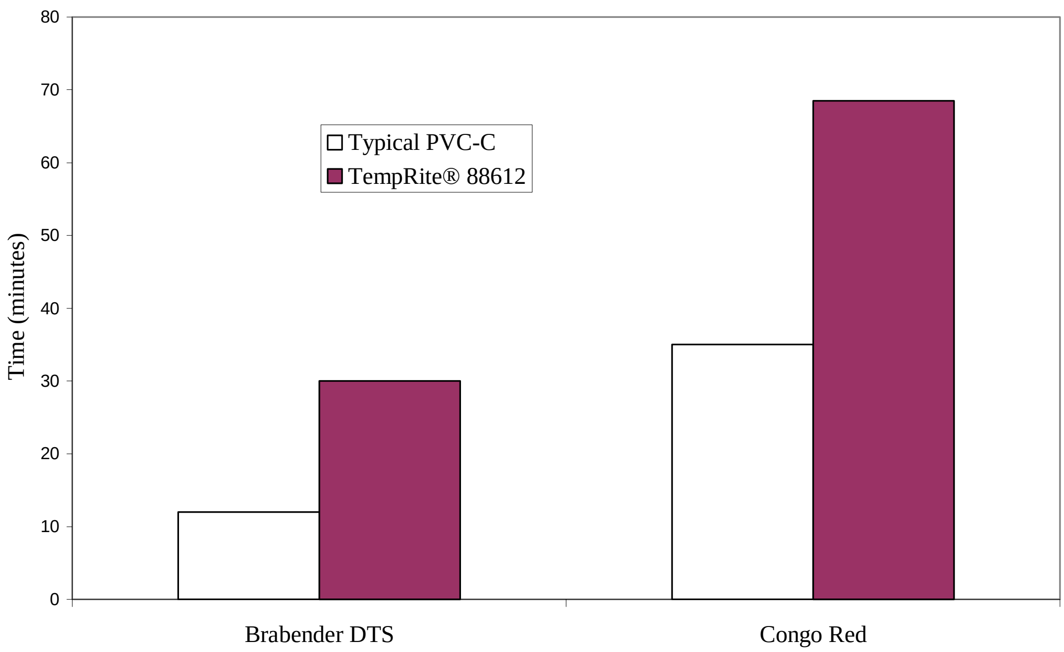


Large Diameter Pipe
Until recently, direct extrusion of PVC-C pipe larger than 12" SCH80 (325x17 mm) was difficult and generally not performed. The primary reason for this was the lack of stability of the compound during processing. In comparison, PVC pipes as large as 24" (610 mm) in diameter are often produced without much difficulty. The reason for this difference is due to the fact that PVC-C is often processed at higher stock temperatures and is more shear

sensitive than PVC. However, recent technological advances have led to the development of a new PVC-C compound that can be processed into pipes up to 20" SCH80 (510x26 mm), and possibly even larger.

TempRite® 88612 is a new PVC-C compound specifically designed to allow for the production of large diameter pipes. Based on the statistical design and analysis study previously discussed, it can be seen that the two main factors that govern thermal stability are the stabilizer and lubricant content. Accordingly, a more thermally stable product was hence developed. Characterization of the dynamic thermal stability of this material was conducted by both Brabender rheometery and Congo Red. Figure 2 shows that TempRite 88612 has significantly more stability compared to other PVC-C pipe compounds. In addition, static testing by oven aging was also conducted and likewise showed similar type behavior. Based on these findings, several large diameter processing trials were subsequently conducted. To date, this material has been successfully extruded into 20" SCH80 (510x26 mm) pipe, the largest known to ever have been produced.

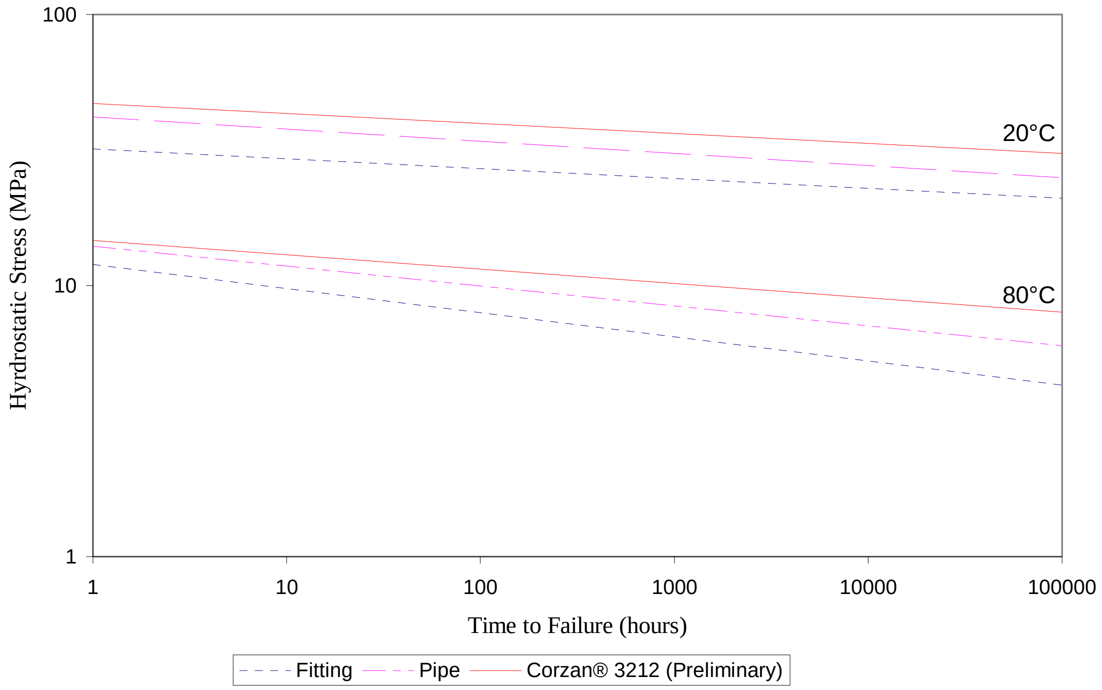
FIGURE 2
Thermal Stability



Pressure Rated Fittings

Unlike pipe, both PVC and PVC-C molding compounds are generally not pressure rated or are rated at a lower stress level. The reason for this is due to the fact that fittings based compounds typically utilize a lower IV (i.e., lower M_w) resin to allow the material to be injection moldable. In order to compensate for this difference the wall dimensions of a fitting are designed to be thicker than that of corresponding size pipe. Recently, however, the hydrostatic strength of Corzan 3212 has been evaluated. To date, over 10,000 hours of testing has been conducted without any signs of non-linearity in the data. Analysis of the data according to ASTM D-2837 reveals that this material has a Hydrostatic Design Basis (HDB) rating of 4,000 psi (27.6 MPa) at ambient temperature and 1,000 psi (6.9 MPa) at 82°C. Figure 3 shows that the hydrostatic strength curves for Corzan 3212 are correspondingly higher than the reference curves for both PVC-C fitting and pipe compounds. This material has been subsequently granted a preliminary pressure rating which is the same as PVC-C pipe by the Plastic Pipe Institute (PPI).

FIGURE 3
Hydrostatic Strength Reference Curves for CPVC



<u>Acknowledgements</u>

The authors would like to thank Noveon, Inc. for allowing this work to be presented and to many other people within the TempRite organization whose hard work and dedication made all of these efforts possible.