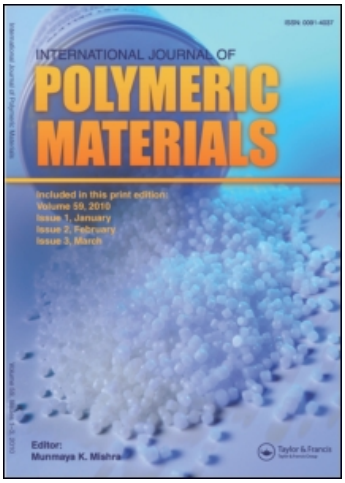

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

Influence of Some Processing Conditions on the Force of Adhesion in the Cable Covering Process

S. Piccarolo[a]; G. Titomanlio[a]
[a] Istituto di Ingegneria Chimica, Palermo, Italy

To cite this Article Piccarolo, S. and Titomanlio, G.(1984) 'Influence of Some Processing Conditions on the Force of Adhesion in the Cable Covering Process', International Journal of Polymeric Materials, 10: 4, 241 — 248
To link to this Article: DOI: 10.1080/00914038408078643
URL: http://dx.doi.org/10.1080/00914038408078643

Intern. J. Polymeric Mater., 1984, Vol. 10, pp. 241–248
0091–4037/84/1004–0241 $18.50/0

Printed in the United Kingdom

Influence of Some Processing Conditions on the Force of Adhesion in the Cable Covering Process

S. PICCAROLO and G. TITOMANLIO

Istituto di Ingegneria Chimica, Palermo, Italy

(Received August 12, 1983)

A simple laboratory equipment has been used to simulate the cooling after extrusion of coaxial cables. The force of adhesion has been measured as a function of polymer viscosity, pressure and cooling conditions. A dimensional analysis has been performed which allows identification of the parameters governing the phenomenon.

INTRODUCTION

In the cable manufacturing practice the dielectric insulation, usually polyethylene, is extruded over the copper conductor containing a steel wire in the center to function as a load carrying member. The adhesion between the outer polymer shell and the conductor must be strong enough to prevent slippage during cable lay out. The force required to slide the polymer from the conductor is called the force of adhesion. This force is made of two different contributions. One is a conventional interfacial adhesion such as exists between bonded surfaces, the other, the major one, arises from the grip afforded by the radial compressive force developed as the polymer shrinks onto the center conductor.

Large variations have been observed in the adhesion values obtained from manufactured cables depending on processing conditions, material properties and on the interval from time of manufacture to the adhesion testing itself (1).

In this work a simple laboratory technique is used to simulate the cooling after extrusion of coaxial cables. Some of the variables affecting the grip of dielectric upon the inner conductor are explored. A qualitative analysis of the phenomena influencing the frictional gripping force is then attempted through a dimensional approach.

EXPERIMENTAL

The apparatus used to simulate the cooling after extrusion in the cable covering process, similar to that previously described in Refs. 2–3, is shown in Figure 1. It is made up of following parts:

—A glass cylinder, with a chromium plated brass rod fastened along its axis, mounted vertically in an oven. Through a hole on the bottom of the oven, the cylinder, filled with molten polymer, was lowered into a cooling bath with constant velocity, thus simulating the extrusion of a coaxial cable.
—A piston-plus-vacuum system for compacting and degassing the polymer in the cylinder. Before starting the "extrusion" experiment this system is removed.
—A device for applying a constant pressure to the molten polymer in the cylinder, which is active throughout the extrusion phase.

In these experiments the following variables were explored:

—the polymer viscosity, η. Two grades of HDPE were used having zero-shear viscosities at 140°C of ca. 4×10^4 and 3×10^5 poises.
—the "extrusion" velocity, V, which was varied between 0.1 and 4 cm/min.
—the operating pressure, P. Pressures of 1 and 10 Ata (absolute pressure) have been used.

For all the tests the brass rod and the internal glass cylinder radii were $R_b = 0.2$ cm and $R = 0.62$ cm respectively, furthermore the

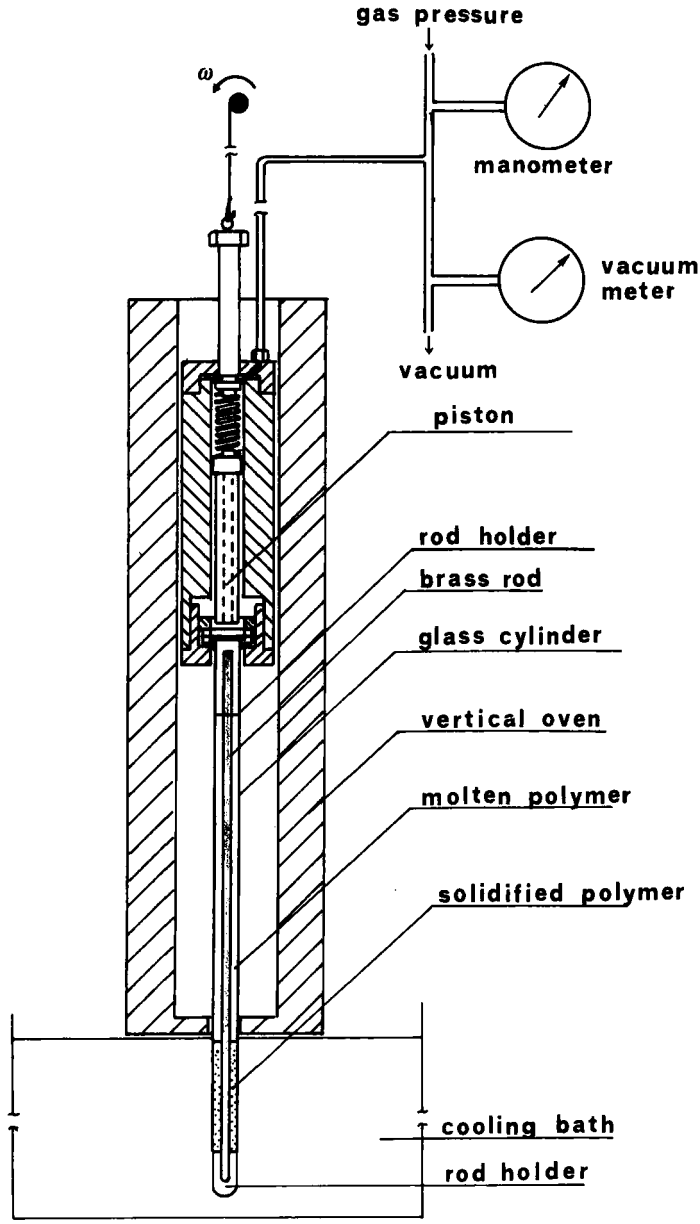

FIGURE 1 Schematic drawing of the apparatus.

oven and the cooling bath have been kept at temperatures of 200°C and 0°C respectively.

The force required to slide the dielectric off the center conductor has been evaluated using a fixture which pulls the inner conductor through a hole in a steel plate which restrains the dielectric. Almost the same technique was adopted previously by Daane,[1] who observed that the gripping force increase was remarkably slower than the sample length. This feature was due to the radial compressive load which arises on the sample extreme during the test. Because of the accurate surface finish, much lower forces were measured in this work, nevertheless the gripping force per unit length resulted still dependent on sample length. Samples of constant length (10 cm) were therefore used throughout, these have been cut from the extruded ones by a water cooled diamond saw. The cut end of the specimens were carefully polished in order to avoid burs influencing the test results. In measuring the gripping force while pulling the brass rod a small force drop was often observed at the sliding start. As the force drop was found about proportional to the total force and furthermore it repeated on restarting the test after a stop, it was ascribed to a static friction coefficient rather than to adhesion bonding.

RESULTS AND DISCUSSION

The total gripping force per unit length, F, is reported in Figures 2 and 3 as a function of "extrusion" velocity, V. For the higher viscosity polymer tests were performed at 1 and 10 Ata, while, for the lower viscosity one, data were taken only at 1 Ata.

The three sets of data indicate that the gripping force decreases towards values close to zero as the "extrusion" velocity increases. In fact by adopting velocities greater than those considered in Figures 2 and 3 even voids were observed close to the center conductor.[4] Furthermore the data reported in Figure 2 show that larger forces are obtained by increasing the operating pressure.

Preliminary to a dimensional analysis, the phenomena taking place during the cooling process need to be briefly discussed. When the sample enters the cooling bath, solidification starts from the outer part and gradually penetrates towards the center; a solidifica-

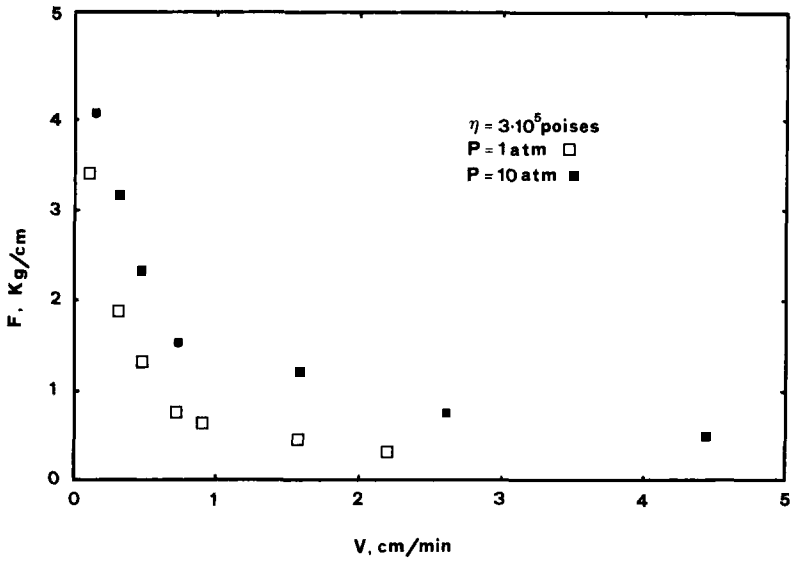

FIGURE 2 Gripping force per unit sample length vs. "extrusion" velocity.

tion front, having length proportional to the advancing velocity, will form in the polymer. The density increase related to the solidification process has the effect of decreasing the pressure inside the cavity bounded by the solidification front and thus a compensating flow arises which is driven by the difference in pressure. If the compensating flow is not sufficient, negative pressures can arise which can even cause formation of voids.[4]

The final step of the process is the restrained "shrinkage" of the solid polymer onto the center conductor in cooling from the crystallization temperature; this shirinkage is directly related to the pressure at the interface polymer-conductor and thus to the gripping force.

Apart from the solid properties which play a significant role in the final step, the gripping pressure depends upon all the factors which regulate the cavity length, its shape and the pressure distribution inside it. In particular a dimensional analysis should account of

—variables describing the geometry: sample radius R, radius of the center brass rod, R_b

—variables which regulate the shape and length of the cavity: advancing velocity in the cooling bath, V; thermal diffusivities of the solid polymer, α, of the melt, α', and of the brass rod, α''; contraction coefficient upon solidification, β; Stefan number, $(c_p \Delta T)/\lambda$

—variables regulating the pressure distribution inside the cavity: V, β, polymer viscosity, η; operating pressure, P

—variables regulating the pressure on the polymer-conductor interface as result of restrained "shrinkage" of the solid polymer from the crystallization temperature, T_m: modulus, E; volume contraction, ψ, upon the temperature difference $T_m - T_a$, i.e. $\delta(T_m - T_a)$, where δ is the volume thermal expansion coefficient

All these variables contribute to some extent to the final pressure, P_g, on the surface between the solid polymer and the axial conductor. Ten independent dimensionless groups can be formed, a possible choice is

$$C = \frac{P_g}{E}; \quad A_1 = \frac{\alpha}{\alpha'}; \quad A_2 = \frac{\alpha}{\alpha''}; \quad B = \frac{R}{R_b}; \quad \psi; \quad \beta;$$

$$S = \frac{c_p \Delta T}{\lambda}; \quad D = \frac{P}{E}; \quad X = \frac{PR^2}{\eta\alpha}; \quad Y = \frac{VR}{\alpha} \qquad (1)$$

The groups A_1, A_2, B, ψ, β, S are constant for the experiments performed. The group C, that is the pressure P_g normalized by the material modulus, can thus be expressed as a function of the remaining three. In place of C, one can consider the group $G = F/(2\pi R_b E)$ i.e. the pulling force per unit surface normalized by the modulus, which can be easily assessed from the data and is proportional to C by the friction coefficient (considered constant here as the brass rods were all simultaneously plated).

Within each of the three sets of data reported in Figures 2 and 3, X is constant, and the data show that the gripping force and thus G increases with X; furthermore by comparing the data relative to the more viscous polymer at an operating pressure of 10 Ata with those obtained with the less viscous one (1 Ata), both having about the same value of X, the effect of D on G can be recognized as minor compared to that of X and Y.

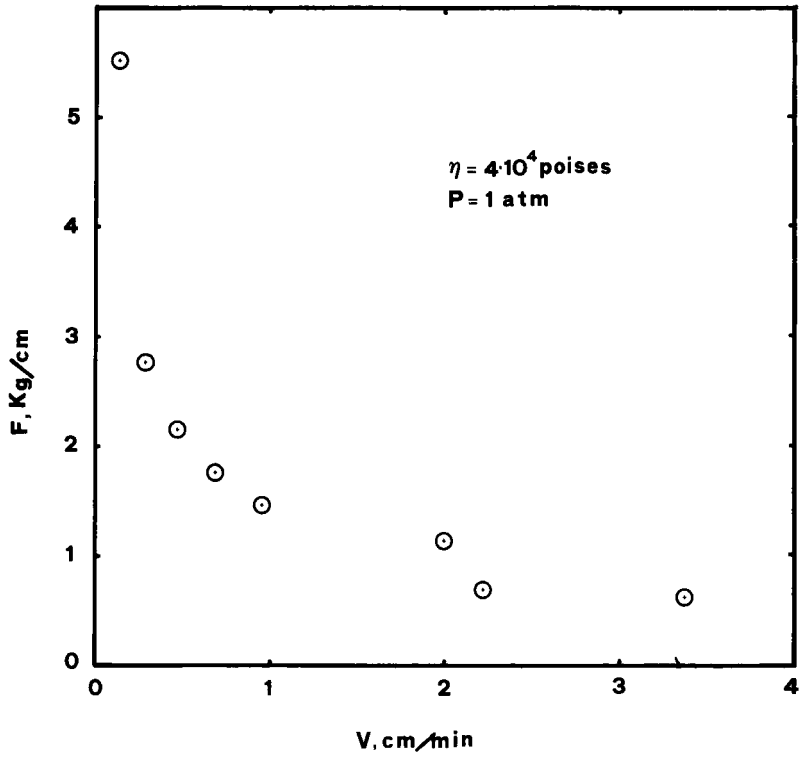

FIGURE 3 Gripping force per unit sample length vs. "extrusion" velocity.

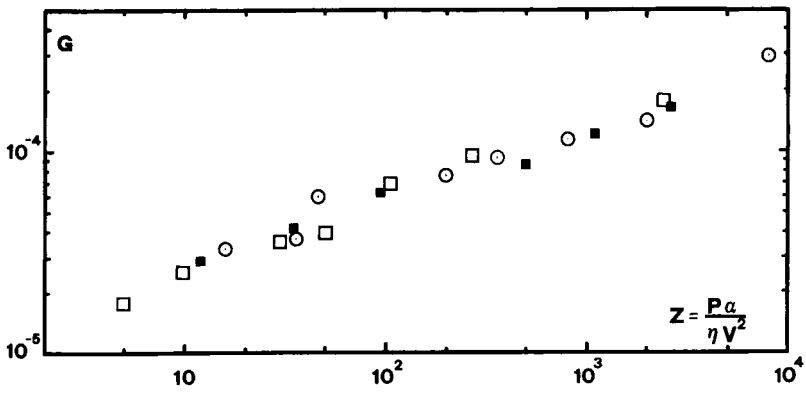

FIGURE 4 Master gripping force curve. Key to symbols as in Figures 2 and 3.

For the pressure distribution, $p(\zeta)$, inside the cavity, the equation

$$\frac{p(\zeta)}{P} = 1 - \frac{X}{Y^2} f(\zeta, B) \tag{2}$$

was recently[4] obtained, where ζ is the axial dimensionless cavity coordinate ($\zeta = 0$ and $\zeta = 1$ at the cavity entrance and tip respectively). Eq. 2 states that the shape of the pressure distribution inside the cavity depends on the group

$$Z = \frac{X}{Y^2} = \frac{P\alpha}{\eta V^2} \tag{3}$$

The group G is plotted in Figure 4 versus Z. The data are satisfactorily described by Z which appear to be the only significant group at least as far as the range of parameters explored here is concerned. The correlation of Figure 4 can be taken as the starting point for a wider investigation both on the variables already considered and on those held constant in this work.

Acknowledgement

This work has been supported by C.N.R. Grant N. CT 82.00852.03

References

1. J. H. Daane, "Factors affecting the grip of dielectric core within submarine coaxial cables", Proc. XXIV Int'l Wire and Cable Symposium, Cherry Hill N.J. Nov. 1975, p. 75.
2. G. Titomanlio, S. Piccarolo and G. Marrucci, "Void Formation in Extruded Bars", European Meeting on Polymer Processing and Properties, Capri, Italy, June 1983.
3. G. Titomanlio, S. Piccarolo and G. Marrucci, "Analysis of Void Formation in Extruded Bars", to be published in *Polym. Eng. & Sci.*
4. G. Titomanlio, S. Piccarolo, "Void Formation in Extruded Manufacts", VI Convegno Italiano di Scienza delle Macromolecole, Pisa, Italy, October 1983.