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Influence of Sheet Extensibility on Tearing Strength

by

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A report submitted
to James E. Kline
in fulfillment of
the requirements for
Course 471

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ABSTRACT

This paper investigates the possibility that there is a relationship between the tearing properties and elongation properties of a sheet of paper. A lack of specific information in the literature and the advent of the in-plane tear method contributed to the need for work to be done in this area. Pulp was prepared according to TAPPI Standards and handsheets formed on a Noble and Wood sheet mold. After wet pressing, sheets were stretched with a hand made device to varying degrees, and dried in an oven in the stretched position. An Instron machine was used to determine the percent elongation, tensile energy absorption, and in-plane tear. An Elmendorf tear tester was used, also to determine tear. The results showed the in-plane tear to be very sensitive to elongation while the Elmendorf tear was not as sensitive. However, in both cases the tear did increase with an increase in sheet elongation. The reason for this occurring was due to more energy being dissipated throughout the sheet as the elongation increased.

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HISTORICAL BACKGROUND AND DEVELOPMENT OF THE PROBLEM

In a study headed by Van Den Akker (1), it was reported that tear is proportional to the work involved in pulling fibers out of entanglement in the sheet, and in the case of well bonded fibers, in rupturing the fibers themselves. More work is involved in pulling out fibers than rupturing them. The initial rise in the tear strength-beating time curve is due to the fact that, in the initial stages of beating, the "frictional drag work" increases by virtue of tighter enmeshment caused by slightly increased bonding, during which time only a negligible number of fibers fail in tensile rupture. As the beating continues, however, more fibers fail in tensile rupture and therefore, fewer fibers are pulled intact from the mesh. Since the frictional drag work per fiber is very much greater than the rupture work, this decrease in the number of fibers pulled intact from the mesh causes the tearing strength to decrease.

The work involved in pulling fibers out of entanglement may not all be due to frictional drag work exclusively. The entanglement should make the sheet more elastic due to its random order. Before fibers are pulled out,

the sheet could be stretched until more work is required to stretch than pull fibers out. It seems apparent that the tearing strength is a combination of the work required to stretch the sheet, pull fibers out of entanglement, and rupture fibers. The relative importance of these three factors would depend upon how the stock was prepared and the sheet formed.

In previous work (2), Wahlberg reported that the greater the shrinkage of a sheet during drying the more extensible the sheet becomes, thus resulting in an increased tear. To prove this, Wahlberg applied stresses to different sheets during drying and reported that an increase of 0.2 kg/cm, width stress, from 0.1 to 0.3 kg/cm, decreased the tear factor from 84 to 78%. This was explained by the fact that the paper was more brittle and less pliable after stretching. After shrinkage occurred the sheet was said to be micro-creped. Micro-creping is obtained by allowing a sheet to shrink during drying, causing extensibility to increase. After micro-creping the sheet is supposed to be of the same general nature as that of creped-paper. It was also reported that the higher the tension applied to a drying sheet the lower the resulting micro-creping and tear. Due to micro-creping a sudden shock can be distributed without piling up stress at one place.

In another study (3), moderate machine tension caused an increase in machine direction tensile. The same tension

caused a decrease in burst which was contributed to the decrease in elongation. With high machine tension there was a decrease in machine direction tensile. There was no mention on how sheet elongation affected tearing strength.

Stretching a sheet during drying in the initial stages may align the fibers somewhat and permit better bonding, which would increase the tensile. If this were the case, tear should decrease due to the bonding. If a sheet is not stretched very much during drying, there may result a sheet with fibers in more random order, which would mean more entanglement and result in a higher tear.

Brecht and Imset (4) regard the zone of tearing as extensive, not as a point. In this zone the elemental forces involved in the tearing stress give rise to a moment of force with respect to a point of reference. The theoretical picture is qualitative in the sense that few of the quantities involved can be evaluated. The virtue of the picture is that it shows how extensibility and fiber length influence the size of the tearing zone and, therefore, also the tearing strength. This theory emphasizes the influence on tearing strength of stress concentration in the zone of tearing.

Recently a study was made (5) on the merits of the in-plane tear method. The conclusions were that very small angles of paper cockle resulted in unduly large tensile forces and therefore in improper tearing. If the

jaw span is too large, a significant amount of non-recoverable energy goes into the untorn portions of the specimen, and if the angle is too small, this effect is amplified because of the large tensile forces. An analysis of forces would show that as the angle approaches zero, the forces are resolved to the untorn portion of the sheet. The applied forces are in the plane of the sheet and can therefore cause tensile forces. In the Elmendorf method, the forces are perpendicular to the sheet and therefore do not include any tensile stresses. It was reported that there is no direct relationship between in-plane tear and Elmendorf tear.

Controlling the amount of shrinkage in a sheet during drying will control the extensibility of the dry sheet. If paper were compared to a spring it can be seen that a spring set in a stretched position will have less stretch left than a spring set in a relaxed manner. For this reason, sheets were dried in a certain manner so that finished sheets of varying extensibilities would be obtained. From the theories and findings of previous workers, it was expected that the tearing strength would increase as the extensibility increased.

EXPERIMENTAL

Stock Preparation

A bleached southern softwood kraft was beaten, in a Valley Beater, in accordance with TAPPI Standard T200-Ts-61. The pulp was beaten for forty-five minutes to a Canadian Standard Freeness of four hundred and fifty milliliters.

Sheetmaking, Stretching, and Drying

Handsheets were made on a Noble and Wood sheet mold and weighed ninety-two grams per square meter dry. The sheets were pressed in a Noble and Wood wet press to 37% oven dry matter. Stretching of the wet sheet was accomplished with a homemade device. Two wide clamps were used, one was fastened to a board and the other one connected to a chain and turnbuckle on the board. After clamping two ends of a sheet, the turnbuckle was tightened until the sheet was stretched to a specified length. With the sheet clamped in this position, it was put into a forced draft oven at 254° F. for five minutes. After drying, the sheets were placed in a humidity room, and conditioned to TAPPI Standards.

Testing

Part of the prepared handsheets were tested on the Elmendorf tear tester according to TAPPI Standard T414 M. Four sheets with the same stretching characteristics were tested together. The results were reported in g-cm. This was obtained by multiplying the force, in grams, by the distance torn, 4.3 cm. The reason for this was to make the Elmendorf values comparable with in-plane values. The in-plane tears were done on an Instron. One sheet, cocked at a six degree angle, was tested at a time. For both methods of tearing, the sheets were torn in a direction perpendicular to the direction the sheets were restrained during drying. Integrator readings on the Instron were used to find the energy per tear. Tensile energy absorption was measured on each sample with the Instron. Elongation was determined along with the T.E.A. test.

DISCUSSION OF DATA

In accordance with the premise of this paper, there seems to be quite a good relationship between tear and sheet extensibility. Figures 1&2 show the in-plane tear markedly increases as the sheet elongation increases while the Elmendorf tear increases at a lower rate. The reason for tear to increase with elongation can be explained by looking at the physical properties of the sheet in the vicinity of the tearing zone. During the tear, fibers are pulled causing them to either rupture or to be pulled from entanglement. In a sheet with little stretch the fibers are rigidly held together resulting in little relative motion of the fibers during tearing. Consequently the stress is applied to the sheet at one location causing a fast rupture of the sheet. A sheet with more stretch has the fibers held in a mat that is not so rigid. One fiber can be pulled and moved, causing another fiber to move in a chain reaction, at the zone of tearing. This relative movement is essentially increasing the width of the tearing zone. By doing this, the forces exerted on the paper can be distributed over a larger area, thus requiring a larger force to be exerted to accomplish the tear. Figures 1&2 show quite clearly that as the sheet elongation increases the tearing strength increases.

When a sheet is dried under unilateral tension, there is a tendency for the fibers to align in the direction of the tension. This alignment causes the fibers to dry in an extended manner. When a tear is propagated perpendicular to the aligned fibers there is a good possibility the fibers will be ruptured and not pulled out of the sheet. Good bonding along the length of the fiber would stop the fiber from being pulled out. Fewer fibers being pulled from the sheet would cause the tear to decrease at a rate proportional to the degree of alignment.

Data from two different beater runs were used to make graphs. Figures 1, 2, & 5 are from one beater run and Figures 2, 4, & 6 are from a second beater run. Tensile energy absorption corresponds qualitatively and theoretically with in-plane tear, but not so well with respect to Elmendorf tear. Figures 1&3 and figures 2&4 display this well. T.E.A. is increased due to the energy required to stretch the sheet before tensile rupture can take place. This is also basically why tearing strength increases with sheet extensibility. Tensile strength, figures 5&6, decreased with increasing elongation because sheet stretching is spread over a longer time period causing fatigue of the sheet, resulting in a lower force required to rupture the sheet. When tensile is run on a sheet with little extensibility the force increases rapidly, which allows a larger force to be applied before rupture occurs. In an extensible sheet many bonds are

broken during stretching, while in a nonextensible sheet most bonds are intact up until the rupture occurs.

The energy values in figure 1 are larger than the respective values in figure 2. This has to be due to the tensile incorporated in the in-plane tear test. The Elmendorf tear does not measure any tensile strength, and therefore should be lower than an in-plane test.

CONCLUSION

Tearing strength has a tendency to increase with increasing sheet extensibility. The in-plane tear test is highly sensitive to elongation, when compared to the Elmendorf tear test. The mechanical nature of the two tests are different and is the cause of the difference in sensitivities.

T.E.A. increased with increasing sheet elongation as did the tear. Energy dissipated throughout the sheet, due to its extensibility, caused both tear and T.E.A. to increase. This is basically why the tensile decreased with increasing elongation. A smaller maximum force was required to rupture a sheet with more extensibility than a sheet with less extensibility.

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FIG. 1

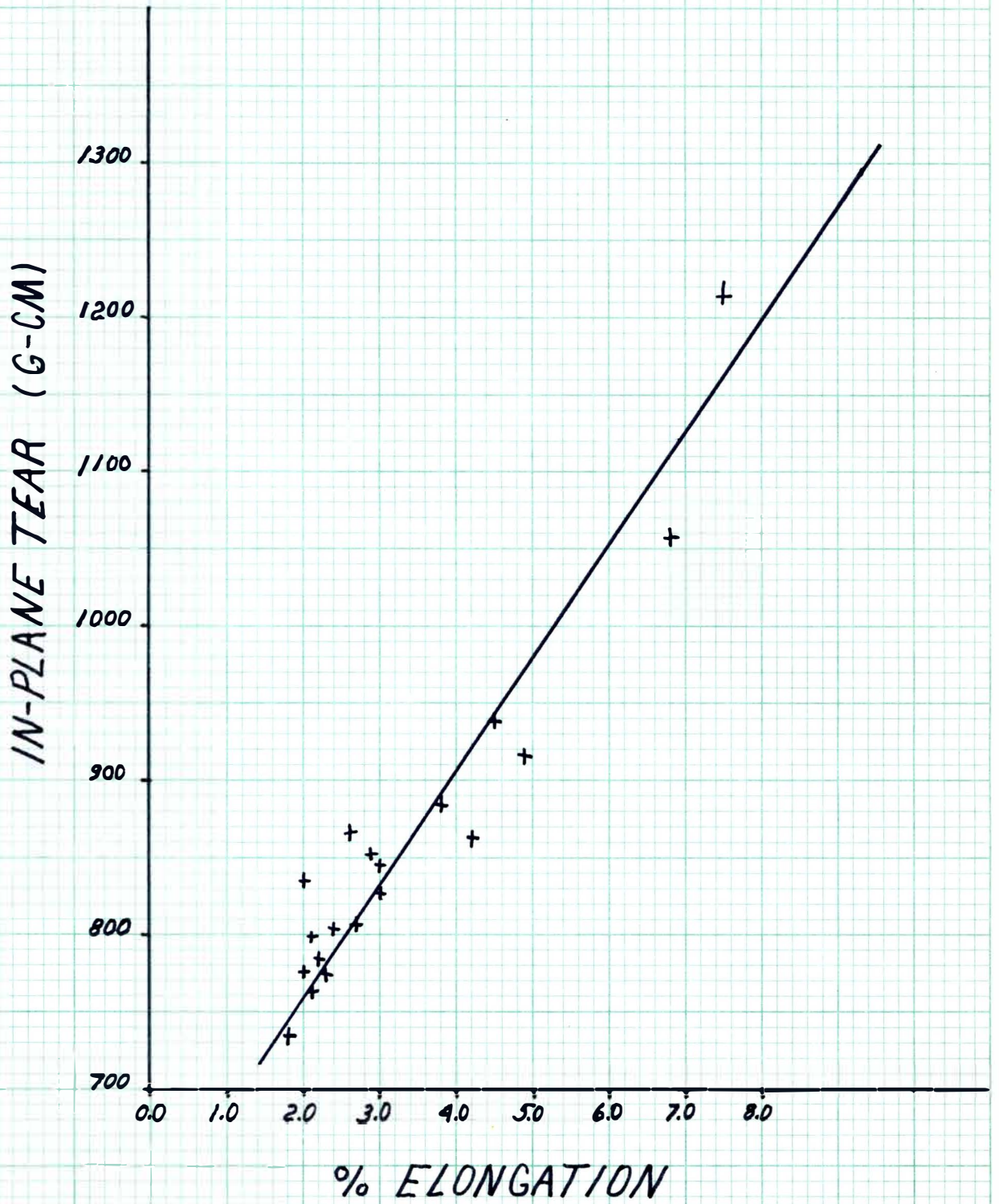
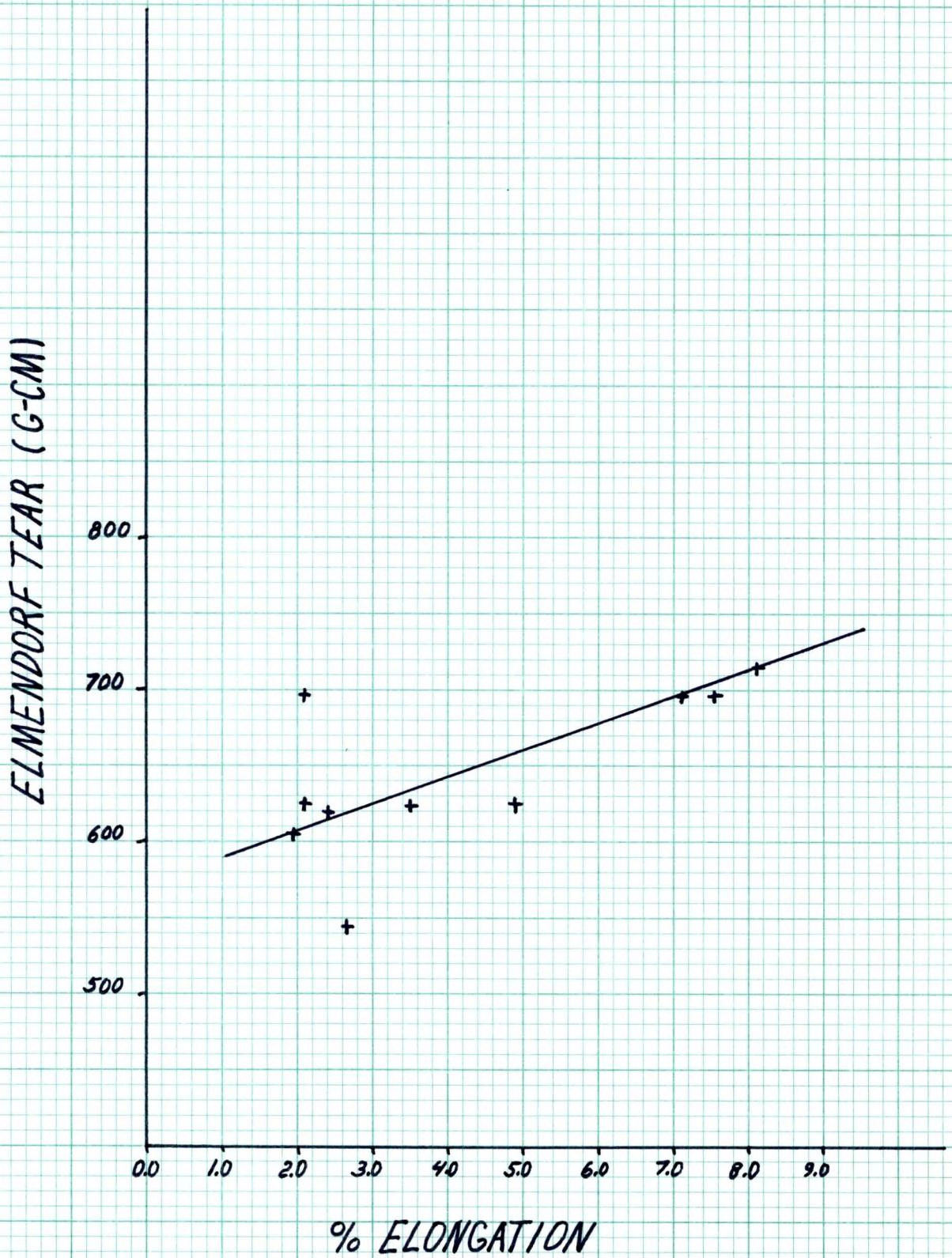


FIG. 2



EFFECTS OF ELONGATION ON T.E.A.

FIG. 3

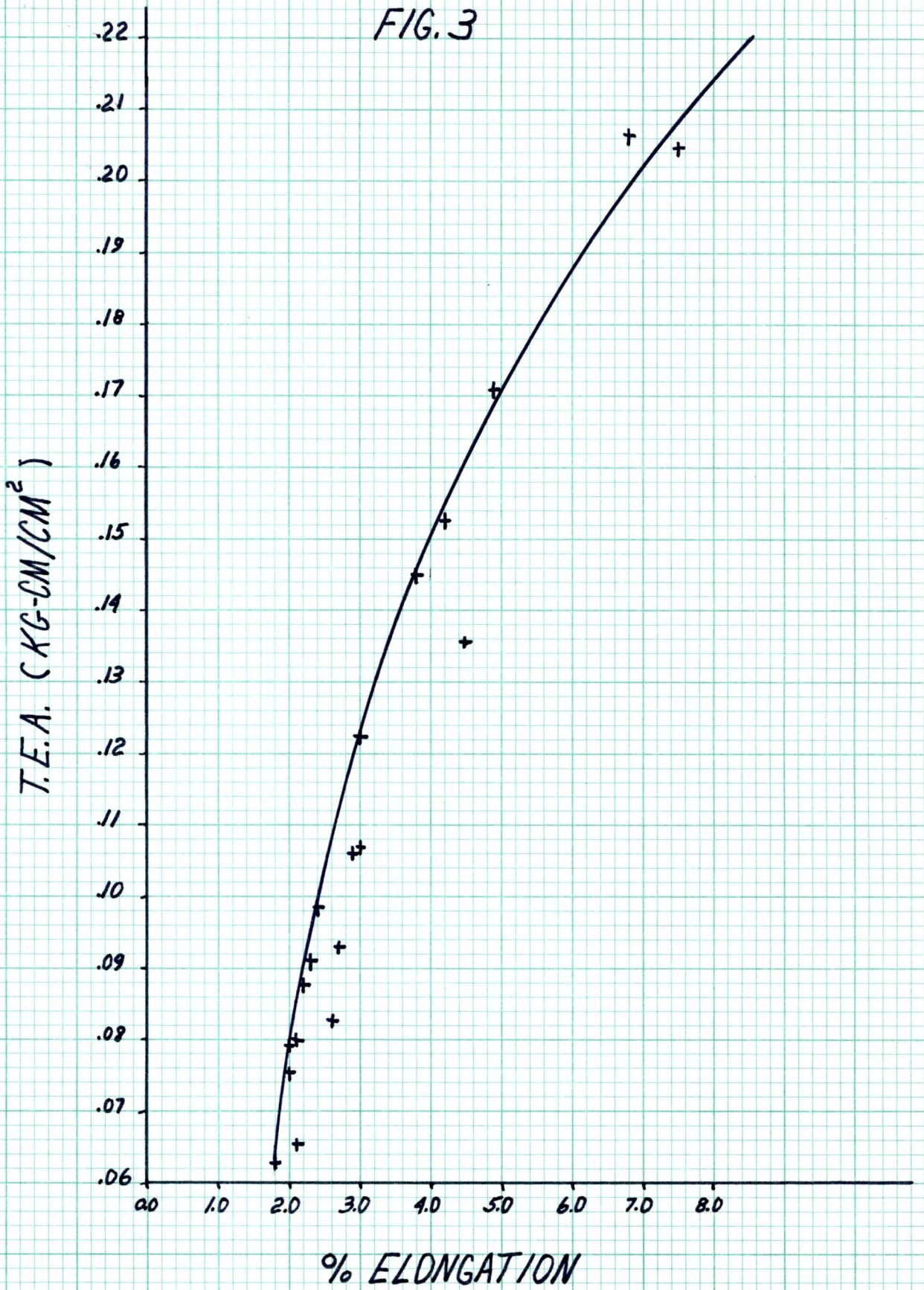


FIG. 4

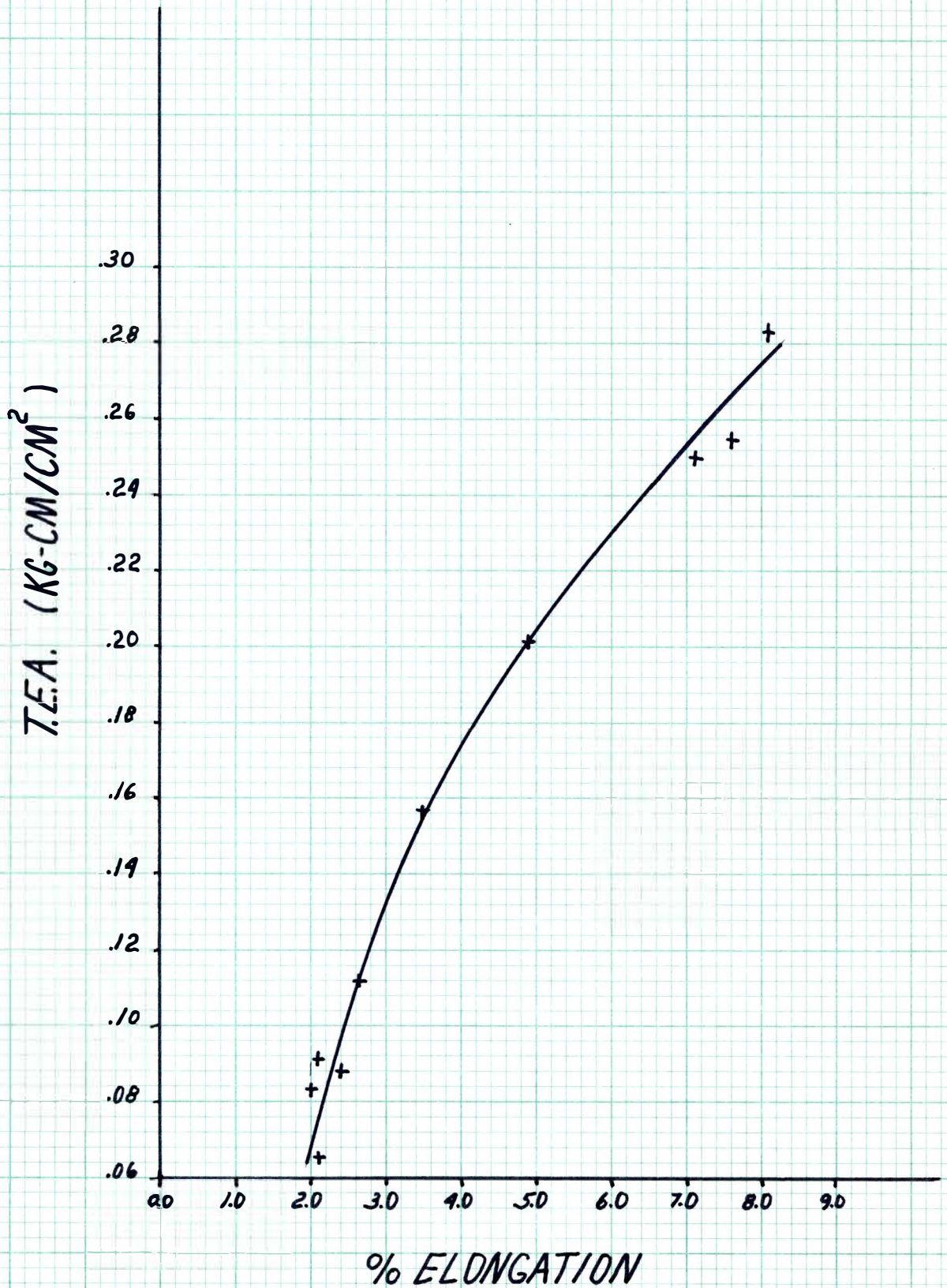
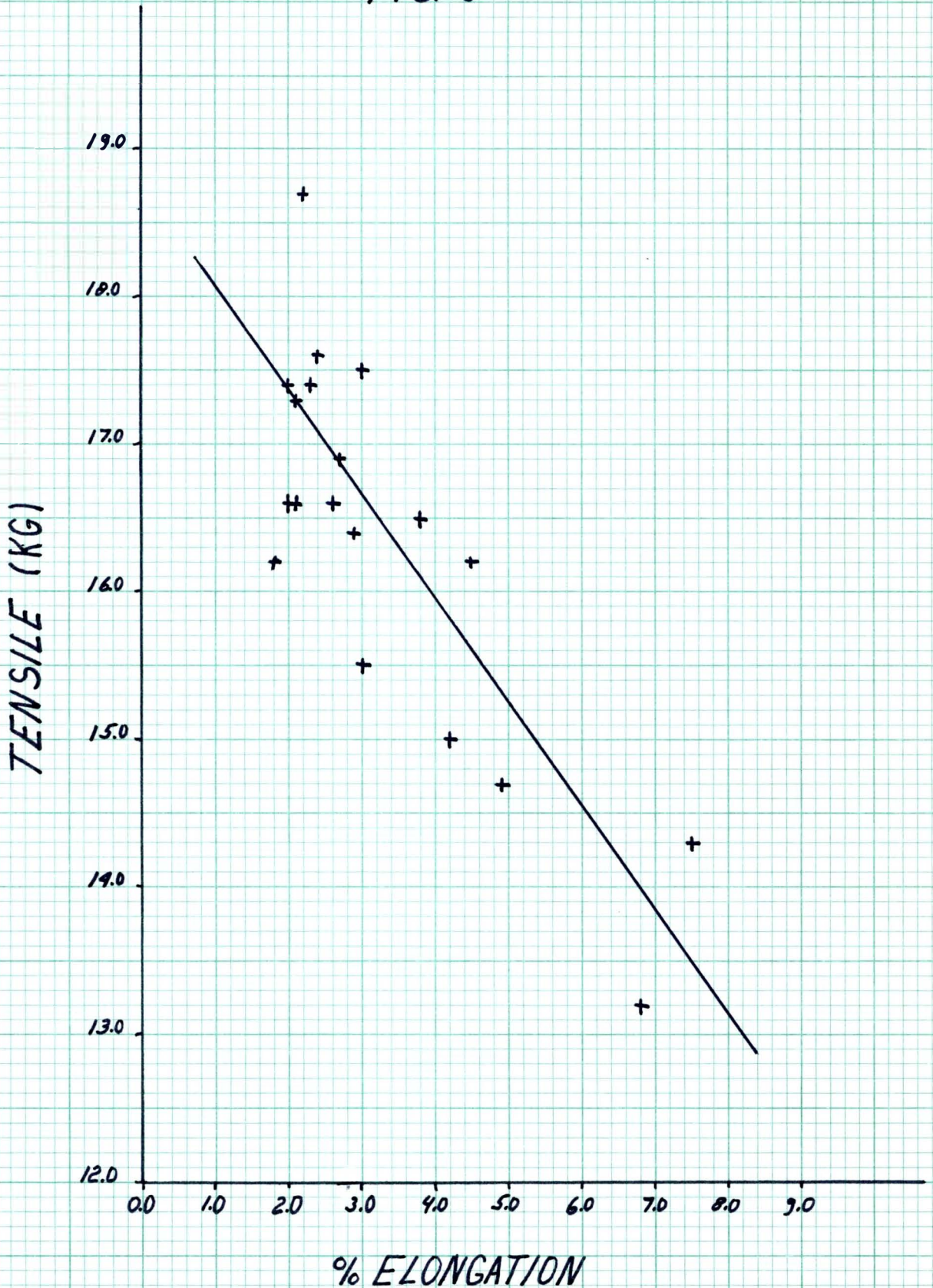


FIG. 5



EFFECTS OF ELONGATION ON TENSILE

FIG. 6

