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The Effects of Basis Weight and Beater Deposited Latex on Fold Endurance

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by

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ABSTRACT

This study was undertaken to investigate the effects of a beater deposited latex on the relationship of basis weight versus fold endurance. An exhaustive survey of past and current literature regarding nearly all aspects of fold endurance as related to basis weight was completed. Two areas of fold endurance were investigated. These were basis weight versus fold endurance for virgin handsheets and basis weight versus fold endurance for sheets containing various levels of beater deposited latex.

The virgin handsheet work served to corroborate past work by others in this area. Fold endurance appeared to become less dependent on basis weight as basis weight increased. Also verified was the duplicity problem when performing fold endurance on the MIT tester. Twenty percent error in a given fold value was not uncommon.

The beater deposition attempts, while yielding no direct information, served to point out the delicate nature of just such an attempt. Several latex/deposition aid systems were tried with only minimal success. This study served to highlight the delicate nature of successful monitoring of the performance of a beater deposited anionic latex.

Future work should include the use of a single component cationic latex system. The use of a cationic material would reduce the number of chemical additives used and should also be self-substantive to the fiber in most papermaking conditions.

INTRODUCTION

The intent of this project was to prove, or disprove, the following hypothesis: a latex impregnated sheet with a higher basis weight and greater initial tensile strength fails faster in fold endurance than a comparable lightweight latex impregnated sheet. Inherent in this project was an investigation of the mechanism of breakage of a sheet in the MIT fold tester. This literature survey focused on three main areas. These were: (1) fold, (2) the effects of basis weight, tensile strength, and fiber length on fold, and (3) the performance of various strength modifiers on fold.

THEORETICAL DISCUSSION

In previous years the fold test was one of the universally accepted test criterion for evaluating paper. Since the late 1950's, the high variability of the fold test results accounted for the fold test's loss of popularity. Clark proposed a new suggested method for the MIT fold test to reduce the variability.[1] Koehler[2], Goldberger and Rhyne[3] also expressed concern with the MIT fold test. Koehler found that fold endurance was greatly affected by changes of the load as long as the changes were no higher than approximately fifty percent of the tensile strength. Snyder and Carson[4] stated that the variation in load tension due to oscillation of the tester during MIT fold was of the order of five percent. This accounts, in part, for the high variability of the MIT fold results. Koehler went on to say, for loads beyond the elastic limit of the sheet, the sheet is irreversibly deformed. Testing within the sheet's elastic limit gave a higher fold than testing beyond the sheet's elastic limit. Goldberger and Rhyne concluded that the most serious drawback of the fold test, as carried out in accordance with TAPPI Standard T 423 M-50,

was that it gave unrealistic results. The paper in the MIT fold test was not actually submitted to pure folding or flexing, but to a combination of folding and tensile stress. The repeated flexing of the sample around the edges of the tester gradually weakened the paper structure until the paper broke under the influence of the tensile load. Due to the fixed load nature of the MIT fold, the test discriminated against lightweight paper. This was because the one kilogram load used in the test was a greater percentage of the lightweight sheet's ultimate tensile strength.

Basis Weight

The effect of basis weight on fold endurance was a critical aspect of this investigation. However, emphasis was placed on just how latex addition fits into the previous work done on basis weight with respect to fold. Much work has been done on "virgin" handsheets by varying basis weight and observing its subsequent impact on fold endurance. Goldberger and Rhyne, working with Cellate and Dryden pulps, did an extensive study on basis weight versus fold. They showed that with increasing basis weight the slope of the fold vs. load line becomes shallower. (They showed that for an upper limit, in their case it was 70 g/m^2, the fold-load relationship becomes more or less independent of the basis weight.) Goldberger and Rhyne also found that under constant load, the fold endurance increased asymptotically to a maximum value at higher basis weights.

Mathematical Expression for Fold

Many people have worked on developing a mathematical relationship for fold vs. load and fold vs. sheet tensile. VanNederveen and VanRoyen[5] showed that the loss in tensile strength after a certain number of double folds in the samples led to the conclusion that this loss in strength is

a linear function of the logarithm of the number of double folds. Wahlberg substantiated the above by concluding that the logarithm of load vs. the logarithm of the folding endurance gave a linear relationship. Again, let it be emphasized that the above relationships were drawn using "virgin" sheets. VanNederveen and VanRoyen[7], in subsequent work, explored the possibility of setting up a mathematical expression for folding resistance. Their formula related fold as an exponential function of other paper characteristics and therefore, helped to explain the large error inherent in determining fold number. Tensile strength was a big factor in the above relationship.

Tensile Strength

Wahlberg[6] felt that there was no relationship between the limiting value of applied fold tension and the sheet's ultimate tensile strength. His reasoning was that the ultimate strength of paper is dependent to a large extent on how it is measured. Further, the bending of a strip is quite different in nature from quasistatic drawing. Krohnstad[8], working with a P.F.I. folding tester supplied with additional weights, showed that the prolonged curves in a diagram obtained when testing paper at different loads gave the intrinsic values which theoretically indicated the number of double folds obtained at zero load, i.e. the load necessary to obtain a zero folding number. Regardless of which school of thought is correct, it is evident that tensile strength exerts a large influence on fold endurance.

Fiber Length

Goldsmith, Valerie, and Higgins[9], in 1954, blamed part of the fold test variability on fiber length. They felt that moisture content and basis weight variations were insufficient to cause the large percentage

standard deviations. Their work showed that fiber length was found to exert a very critical influence in folding endurance. Fiber length variation within marked samples helped to explain the fold endurance variance between these samples. This indicated that even with strict control of basis weight and moisture content, fold endurance persists to show rather poor repeatability on a given sample. A basic law of statistics states that to decrease data error by a factor of two, the sample size must be increased by a factor of four.[10] This implies that for reliable fold experiments large sample sizes are necessary.

The preceding was a review of the work done concerning folding endurance of a sheet of paper. Basis weight increase increases fold endurance. Initial sheet tensile causes a direct relationship in fold endurance. What now needs to be introduced into the discussion is the effect of a bond strength improver on fold endurance as it relates to basis weight.

Latex

Much work has been done and many patents have been issued describing processes for improving sheet strength with the addition of different polymer latices into the sheet network. Leavitt, Andrews, and Stannett[11], Gelbert[12], Kelly and McLaughlin[13], Sterling[14], Heyse, Sarkanen, and Stannett[15], and MacGugn[16] have all explored the effects of different latices on fold performance. They all agreed that the addition of a bond strength improver to paper increased its fold endurance. Work done by Garland[17] in 1967, showed that for higher weight paper, the latices, specifically neoprene and urethane, increased the sheet's extensibility but reduced the folding endurance. What remains to be determined is the shape of the curve relating basis weight and fold for latex-treated papers.

The relationship between fold endurance and basis weight for "virgin"

handsheets has been fairly well defined. Lightweight or normal handsheet weight paper has been treated with latex and the resulting increase in fold has been documented. "Heavy" sheets, as used in the area of boxboard or shoeboard weight, have shown a loss in fold endurance. An explanation of this loss in fold endurance in heavy sheets was investigated in this study.

Several physical phenomena need to be investigated. A specific bond strength improver, in this case the aforementioned latices, has shown an ability to improve fold endurance. Bolton[18] showed that by adding a "bond number increaser", uncooked oxidized starch, to the sheet, fold endurance was improved. Addition of starch to "heavy" paper also increased fold endurance as well as tensile strength as shown by Garland[17]. It appears then, that part of the loss in fold endurance was due to the latices decreasing the heavy sheet's stress distribution ability. The latices, by improving bond strength, increased the rigidity of the sheet. This decreased the sheet's ability to distribute both the tensile and expansion-contraction stresses occurring at the fold site of the "heavy" sheet.

EXPERIMENTAL PROCEDURE

Experimental procedure compared two types of paper with respect to fold vs. basis weight. A blank paper, containing no additives, was run to duplicate past work and to tune-up experimental procedures. The second type of paper contained a latex to improve bond strength. Enough samples were run to yield statistically valid results. An unbleached softwood Kraft pulp, beaten in the WMU lab valley beater, was used throughout the experiment to minimize problems with fiber length variations. Kahlson and Marlensson[19] showed that when the rise in temperature near the folding zone was eliminated, the high initial fold endurance values

disappear and the coefficient of variation decreases. Unfortunately, there was no fan available in the laboratory to help minimize heat build-up at the fold zone. Care was taken to avoid exceeding the lightweight sheet's elastic limits. This was the limiting factor in basis weight variations with respect to the MIT's one kilogram load.

Blank Sheets

The blank handsheets, those containing no additives, were prepared in the following manner: 345 grams, air dry, of bleached Newbern Softwood Kraft Pulp were added to a laboratory beater full of tap water. The pulp was soaked fifteen minutes in the beater. The pulp was hand-shredded during the last ten minutes of the soaking period. The beating consistency was 1.15% . The beater was run five minutes with the weights off to further disintegrate the pulp. Following the above, the pulp was beaten for one hour with the standard weight on. At this point the corrected Canadian Standard Freeness was 540 ml. The freshly beaten pulp was stored overnight and handsheets were made the following day.

The pulp was diluted to .85 % for ease of measuring. The appropriate amount of stock was measured from a constantly stirred bucket of pulp. This aliquot of stock was poured into a Noble and Wood handsheet mold. The mold contained tap water. The stock in the mold was stirred five times, at a rate of approximately one up/down cycle per second. The mold full of stock was allowed to stabilize for approximately five seconds. The mold was then drained. For pressing the sheets below 200 gm/m^2 basis weight, all the weights were removed. Too much press pressure at the higher weights would lead to excessive web crushing and splattering. Once pressed, the sheets were dried on the Noble and Wood handsheet mold drier. The drier was at 230°F and rotating at one revolution per minute. The sheets above 200 gm/m^2 were sent through the drier twice. Both drying

periods were done with the web on the screen to minimize sheet deformation. The sheets were then conditioned overnight in the constant temperature, constant humidity room.

Sheet weighing was done on a Mettler balance after the sheet moisture content had equilibrated. Sheet caliper was measured in five areas of the sheet using a TMI Model 549 micrometer. An average caliper and standard deviation were calculated. Fold samples were cut using a TMI Precision sample cutter. The fold samples were 15 mm in width. The fold test was done with an MIT fold tester in a constant temperature, constant humidity room. The fold test was done according to the operating guidelines attached to the fold tester. Five fold tests were run per sheet. An average fold and standard deviation were calculated.

Beater Deposition

Initial plans were to use a cationic latex thereby removing the problems of trying to use an anionic latex plus a deposition aid. Unfortunately, this was not to be the case. Rohm and Haas Co. supplied some sample latexes. The first beater deposition was with Rohm and Haas Co. Latex B-15.

The pulp for this segment of the experiment was prepared in the same manner described for the pulp for the blank sheets, the only difference being a beating consistency of 1.27 % and a corrected Canadian Standard Freeness of 524 ml. Latex replacement of pulp was used to maintain a constant basis weight. For a 5 % latex sheet, the sheet composition was 5 % latex and 95 % pulp by weight. An alum solution, 10 % by weight, was used as a deposition aid. Alum was introduced into the system to make the slurry cationic in charge. Tom Drennan of Rohm and Haas Co., recommended a 2 % pulp slurry, an initial addition to the slurry of 4 % alum by weight based on the pulp, addition of the Rhoplex B-15 followed

by a 2 % to 8 % alum solution, (based on the pulp), to complete the latex deposition. Beater deposition was attempted using the following advice.

The actual sheetmaking procedure went as follows. The proper amount of pulp was taken from a constantly stirred bucket and put into a beaker. Four percent alum was added to the slurry and hand stirred for 30 seconds. Next, the proper amount of latex was added to the pulp. The latex was diluted one to one by weight with tap water. The system was hand stirred for one minute. Additional alum was added to complete the latex deposition. Weighing the handsheets and observing the sheet mold drain water were the initial indication that the latex had failed to deposit. Further talks with Rohm and Haas Co. verified that the above system was not conducive to beater deposition of Latex B-15. The amount of alum used was correct but the stirring procedure was incorrect. The initial alum addition should have been mildly agitated for approximately five minutes to allow complete adsorption of the alum by the fibers. The latex should have been added and mildly agitated for ten minutes to allow the bulk of the latex to be adsorbed by the now cationic alum-fiber slurry. The second alum addition would be used to deposit remaining latex in the system onto the fibers. Tap water was used throughout the experiment because Rohm and Hass Co. indicated that latex deposition performed better in hard water. The next latex deposition involved a different latex and deposition aid.

In the next deposition attempt, the pulp used was the same pulp as used for the unsuccessful B-15 trial. The pulp was two days older and diluted to .88% with tap water prior to its use. Kymene 557 was used instead of alum as a deposition aid. For ease of measurement, the Kymene 557 was diluted from 12.5% to .125%. Rhoplex TR 407 diluted one to one by weight from 45.5% solids with tap water was the next latex tried. Kymene 557 was added at 1% on binder solids to the proper aliquot of

pulp. This system was then gently stirred for five minutes to deposit the Kymene 557 onto the fibers. The next step was to add the latex in the amount described for the B-15 trial and mix the slurry 10 minutes at a moderate speed. When necessary, 0.1% Kymene 557 based on pulp solids was added to complete the deposition. Deposition completion was checked by visual observation of pulp-latex slurry. A complete rundown of the handsheet composition is recorded in Table I. Stirring was done with a multiple speed blender. Beaker size was varied as well as blender speed to accomodate the variances in slurry volume. The sheet formation procedure was the same as used for the blank handsheets. The sheets with desired basis weight above 200 gm/m^2 were pressed without any additional weights and dried twice as were the blank handsheets. The sheets were then conditioned overnight in the same constant temperature, constant humidity room as were the blank sheets. Weight, caliper and fold were measured in the same manner as described for the blank sheets. Five fold tests per sheet were run over the course of a week.

RESULTS

The results from the blank handsheets are shown in Table II, Figure 1 and Figure 2. Table II shows the range of basis weights actually achieved. The actual sheet weight in grams, caliper converted to metric, and the area of the sheet combine to yield the density of the handsheet in grams per centimeter cubed. The actual fold values obtained are also displayed in Table II. The standard deviation as a percent of fold is found in the percent error column of Table II. Figures 3 and 4 and Table III are similar to the preceding Figures 1 and 2 and Table II except that they are the results for the latex deposited handsheets. Figure 1 is a graphical representation of the fold vs. basis weight values found in Table II. Sheet fold endurance versus sheet density is shown in Figure 2. Tables I

and III combine to show the extent of latex deposition achieved. Figures 3 and 4 show for the latex deposition sheets fold endurance vs. basis weight and density respectively. The blank handsheets are also represented on Figures 3 and 4.

DISCUSSION

The blank handsheet fold vs. basis weight plot seems to approach a fold value that is independent of basis weight (see Figure1). This is consistent with the findings of Goldberger and Rhyne. However, whereas Goldberger and Rhyne found that fold became independent of basis weight at $70 g/m^2$, this was not the case in this investigation. The slope of the fold vs. basis weight remained fairly steep at a basis weight of $140 g/m^2$. The steep slope of the fold vs. basis weight curve even at $140 g/m^2$ may be due to difficulties in maintaining a constant density as the basis weight increased. The effect of drastic variations in wet press conditions resulted in the high fold endurance for the sample above $200 g/m^2$ basis weight sheet. Density accounted, in part, for the shape of the fold vs. basis weight curve.

Fold vs. density for the blank handsheets is shown in Figure 2. As the density increased the fold endurance asymptotically increased. The combination of increasing basis weight and constant press pressure during handsheet preparation resulted in an increased handsheet density. Figure 2 seems to incicate that small changes in density result in large increases in fold endurance. The extremely high fold endurance point at approximately $.65 g/cm^3$ was due to very high basis weight and relatively high wet pressing.

Careful investigation of Tables I and III leads one to suspect that the amount of latex actually deposited was somewhat less than that desired. Unfortunately, the amount of latex retained in the sheet was not accurately monitored. The best deposition seems to have been achieved

with Sheet 1A at a desired latex level of 10%. Much of the fold strength that is exhibited in Figure 3 for Sheet 1A may be explained by the variations in wet pressing. The lack of effective deposition in the latex impregnated sheets resulted in all statistical reality, the fold endurance characteristic of blank handsheets.

The fold endurance percent error was atrociously large. The absence of a fan used to minimize heat build-up at the fold zone was one factor contributing to the large percent of error. The jaws of the fold tester could not be matched exactly to the caliper changes of the various handsheet. This, as explored by Snyder and Carson, will cause variability in the MIT fold endurance results.

CONCLUSIONS AND RECOMMENDATIONS

In summary, the blank handsheets confirmed past experimentation. It appeared that if density were to remain constant, fold would increase to a level where it would then become independent of basis weight. The latex deposition work, while yielding no significant data directly, did indirectly point out how difficult beater deposition of a latex is. The possible combinations of latexes and deposition aids are practically infinite. Further work should be done on the effective deposition of a latex. Future work could explore the effect of electrophoretic mobility as it relates to the retention of papermaking additives.

SHEET #	DESIRED BASIS WT.	ACTUAL BASIS WT.	ML PULP	PRETREATMENT % KYMENE 557 ON BINDER SOLIDS	ML LATEX/	POST-TREATMENT % KYMENE 557 ON PULP	
				% KYMENE/ML	% LATEX	% KYMENE/ML	% KYMENE/ML
1A	200	225	954	1.0/6.6	3.4/10	0.1/6	0.1/6
2A	200	213	950	0/0	0/0	0/0	0/0
3A	200	212	894	1/13.2	7.3/20	0.1/5.6	0.1/5.6
4A	200	227	1059	0/0	0/0	0/0	0/0
5A	200	148	636	1.0/26.4	14.5/40	0.1/4.0	0.1/4.0
6A	120	142	635	0/0	0/0	0/0	0/0
7A	120	129	572	1.0/3.97	2.18/10	0.1/3.57	0.1/3.57
8A	120	116	508	1.0/7.94	4.36/20	0.1/3.17	0.1/3.17
$8A_1$	120	122	508	2.0/15.88	4.36/20	0.1/3.17	0.1/3.17
9A	120	128	572	2.0/7.94	2.18/10	0.1/3.57	0.1/3.57
10A	120	135	572	2.0/7.94	2.18/10	0.1/3.57	0.1/3.57
11A	120	121	508	2.0/15.88	4.36/20	0.1/3.17	0.1/3.17
12A	60.5	67	320	0/0	0/0	0/0	0/0
13A	60.5	60	286	2.0/3.96	1.09/10	0.1/1.78	0.1/1.78
14A	60.5	56	254	2.0/7.48	2.18/20	0.1/158	0.1/1.58

SHEET #	CALIPER 1/1000"	BASIS WT. g/m^2	WEIGHT GM.	DENSITY g/cm^3	FOLD	% ERROR
1	3.48 ± .044	18.7	.772	.212	11.8 ± 4.92	41.7
2	3.46 ± .089	17.6	.726	.200	6.2 ± 4.82	77.7
3	3.44 ± .054	19.3	.798	.221	10.2 ± 8.93	87.5
4	3.58 ± .044	21.7	.896	.239	31.8 ± 16.5	51.9
5	4.46 ± .054	22.2	.918	.247	33.2 ± 15.9	47.9
6	4.46 ± .054	43.1	1.78	.380	213 ± 51	23.9
7	4.54 ± .054	42.6	1.76	.378	195 ± 54	27.7
8	4.54 ± .054	45.7	1.89	.397	249 ± 83	33.3
9	4.64 ± .114	46.7	1.93	.397	240 ± 34.2	14.2
10	4.52 ± .044	44.0	1.82	.382	236 ± 58	24.6
11	5.46 ± .089	65.3	2.70	.472	368 ± 86	23.4
12	5.44 ± .114	63.9	2.64	.463	446 ± 101	22.6
13	5.80 ± .122	73.6	3.04	.500	413 ± 138	33.4
14	5.40 ± .187	66.6	2.75	.486	414 ± 128	30.9
15	5.40 ± .122	67.8	2.80	.494	467 ± 191	40.9
16	6.72 ± .192	95.3	3.94	.559	630 ± 133	21.1
17	6.98 ± .164	101.2	4.18	.571	694 ± 182	26.2
18	6.58 ± .148	94.1	3.89	.564	653 ± 219	33.5
19	6.82 ± .228	94.6	3.91	.547	596 ± 146	24.5
20	7.06 ± .536	98.5	4.07	.550	732 ± 200	27.3
21	7.50 ± .316	118.9	4.91	.624	710 ± 123	17.3
22	7.88 ± .363	122.0	5.04	.610	852 ± 229	26.9
23	7.70 ± .353	119.8	4.95	.613	679 ± 191	28.1
24	8.02 ± .327	123.2	5.09	.605	793 ± 230	29.0
25	7.76 ± .089	124.0	5.12	.629	861 ± 65	7.55
* 26	13.64 ± .43	224.0	9.27	.648	2286 ± 249	10.9

* NOTE: Severe crushing during wet pressing at basis weights above 200 g/m^2.

LATEX DEPOSITED SHEETS TEST RESULTS

SHEET #	CALIPER 1/1000"	BASIS WT. g/m^2	WEIGHT GM.	DENSITY g/cm^3	FOLD	% ERROR
1A	13.76 ± .45	225	9.30	.644	2193 ± 912	41.6
2A	13.96 ± .13	213	8.79	.600	1466 ± 630	43.0
3A	13.44 ± .13	212	8.78	.623	1252 ± 716	57.2
4A	13.72 ± .34	227	9.38	.652	1686 ± 785	46.6
5A	10.06 ± .24	148	6.12	.580	926 ± 113	12.2
6A	8.72 ± .19	142	5.87	.657	1288 ± 123	9.55
7A	8.52 ± .27	129	5.35	.599	1052 ± 237	22.5
8A	7.92 ± .31	116	4.78	.575	1075 ± 135	12.6
$8A_1$	8.20 ± .28	122	5.05	.587	1144 ± 146	12.8
9A	8.36 ± .20	128	5.29	.603	1060 ± 88	8.30
10A	8.72 ± .22	135	5.59	.611	1251 ± 120	9.59
11A	8.18 ± .41	121	5.01	.584	998 ± 209	20.9
12A	5.30 ± .22	67	2.77	.498	430 ± 57	13.2
13A	5.40 ± .12	60	2.48	.438	344 ± 96	27.9
14A	4.96 ± .27	56	2.32	.446	389 ± 73	18.8

<u>FIGURE 1</u>

FOLD VS. BASIS WEIGHT

FOR BLANK SHEETS

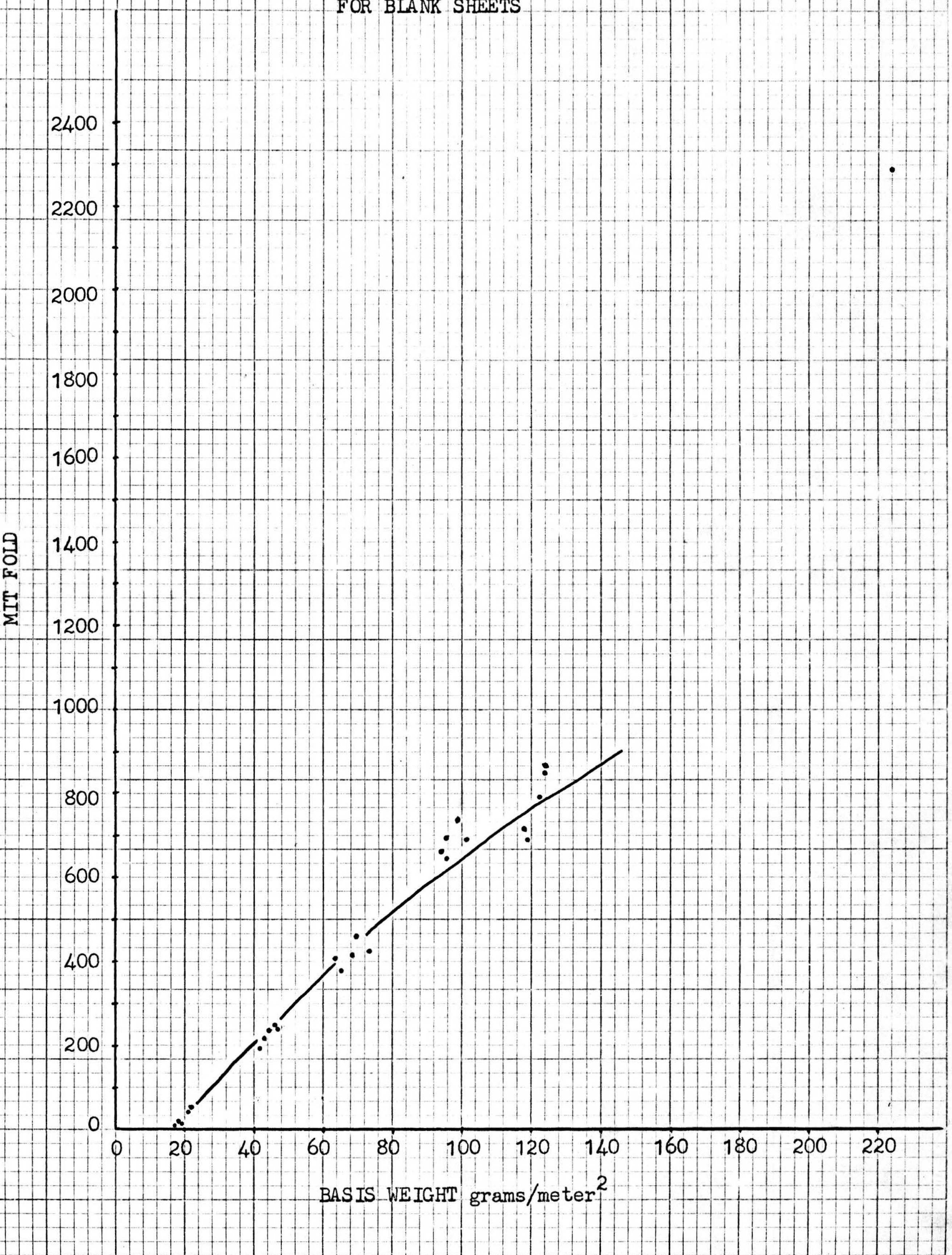


FIGURE 2

FOLD VS. DENSITY

FOR BLANK SHEETS

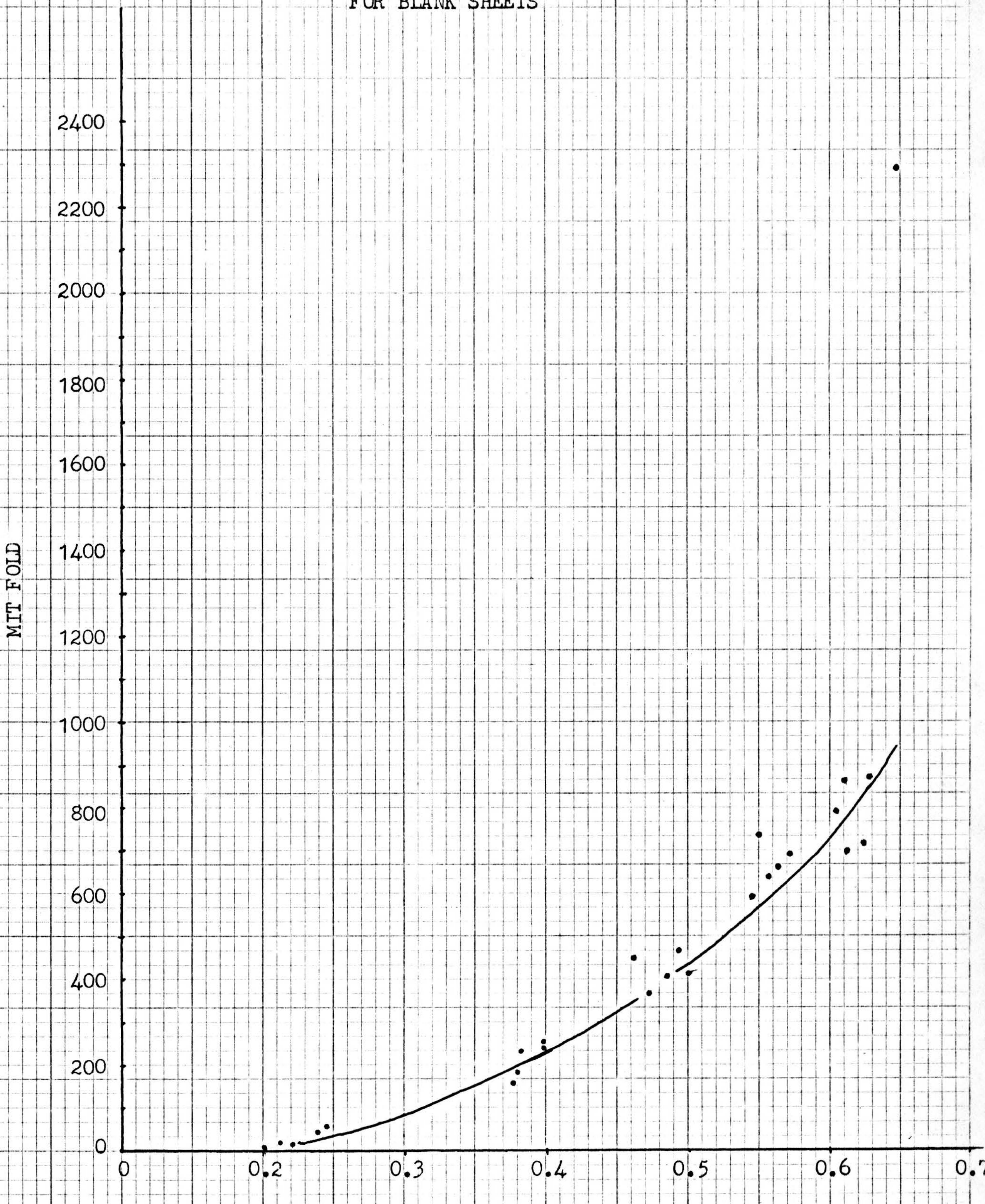
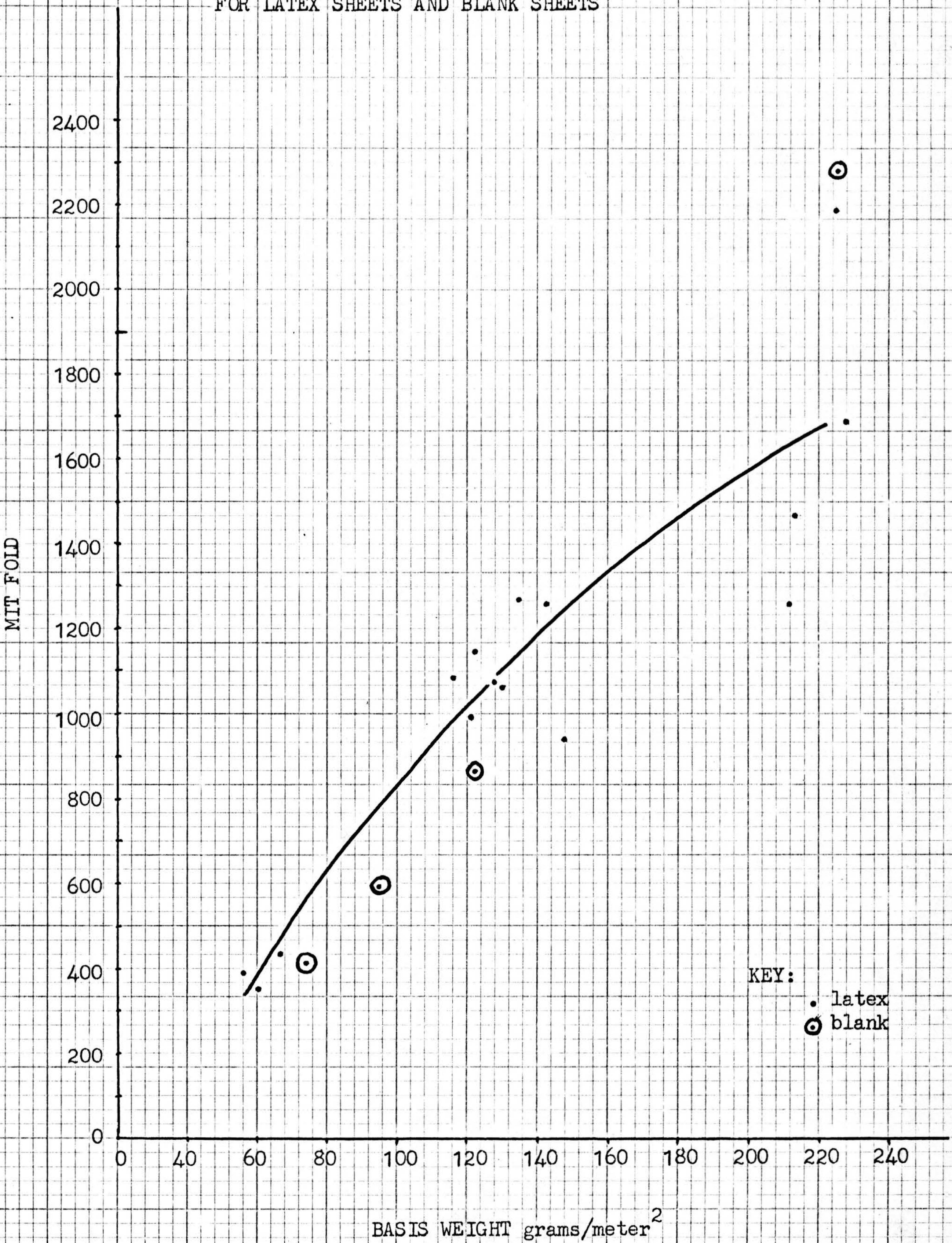


FIGURE 3

FOLD VS. BASIS WEIGHT

FOR LATEX SHEETS AND BLANK SHEETS

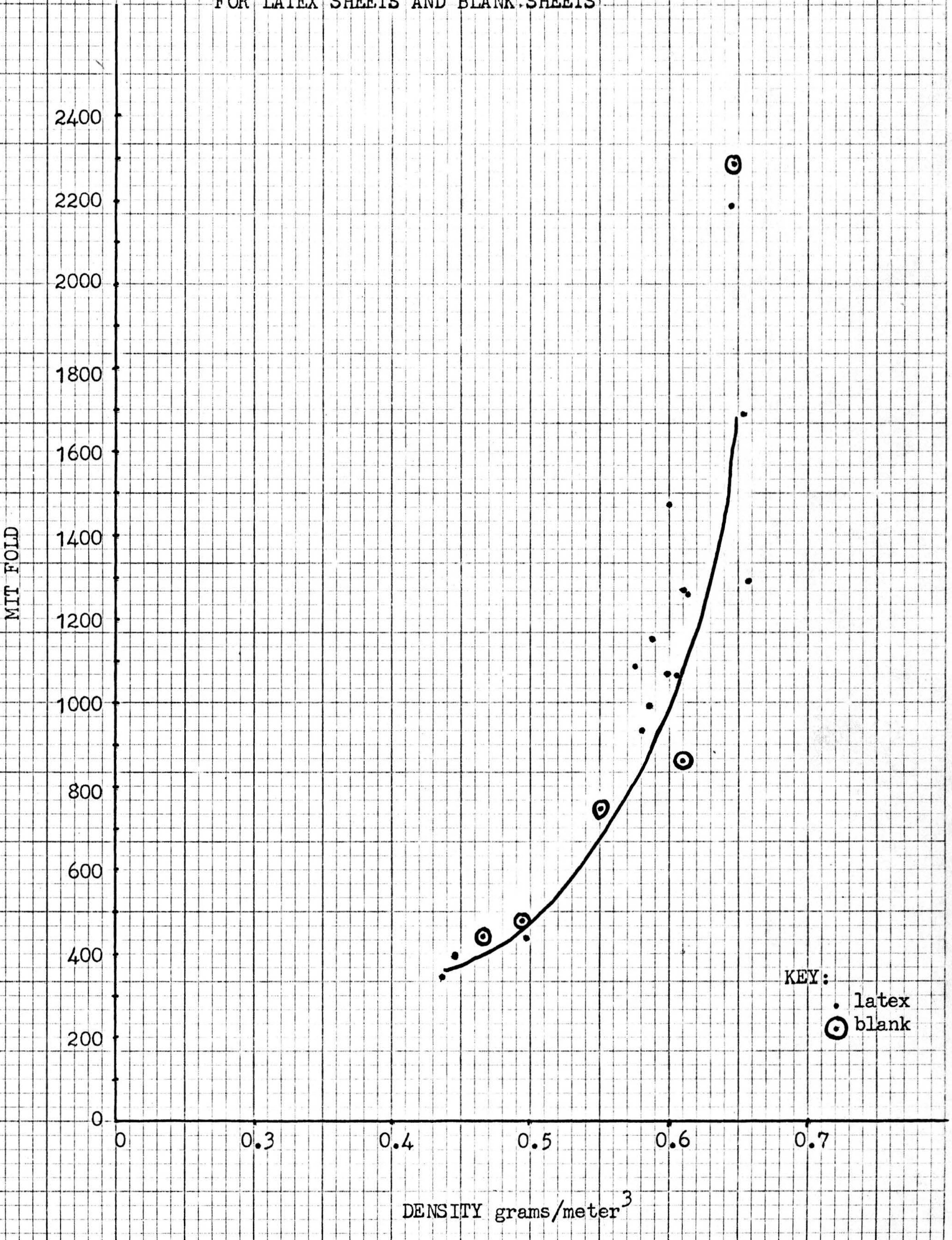


s to the Inch

FIGURE 4

FOLD VS. DENSITY

FOR LATEX SHEETS AND BLANK SHEETS



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