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# An Evaluation of the Factors Affecting Perforation Quality

H W Kropholler and T J Prior
Department of Paper Science, UMIST
Manchester M60 1QD

## ABSTRACT

Samples of two types of cartonboard, a coated white line chip (WLC) and a folding boxboard (FBB), were perforated using an experimental cutting forme. Variations such as depth of cut and rule condition were introduced. These samples were then torn using an Elmendorf tear tester and assessed for their mode of failure. The results indicate that the detrimental effects of worn rules and poor cutting depth can be magnified by the size and relationship of certain board properties, particularly tear and plybond strength. The test results and micrographs suggest an unaided visual examination of the perforated line is insufficient to guarantee clean tearing, particularly when worn rules have been used.

The effect of the pronounced directionality in the WLC has been demonstrated with regards to the perforation performance. The results have also indicated that plybond/tear ratio is significant in the mode of failure. The usefulness of transmitted light coupled with magnification has been shown with respect to the examination of perforations for quality control purposes. This holds possibilities within QC as a method of assessment.

## INTRODUCTION

The total package must fulfil a number of different functions. The most important of these are listed by Paine [1990]. These are containment, protection and preservation, communication, machinability and convenience of use. The importance of these are discussed in BS:1133 section 1 [1989]. Another very important requirement of packaging is that the package design must fit in with the high speed manufacturing, erecting, gluing, filling and sealing operations used in modern manufacturing. Any design, however effective, will be uneconomic unless it can be produced and run on high speed machinery [Paine 1990].

In producing a package from paperboard, the converter is concerned with two major operations. These are printing and cutting and creasing (C&C). In the cutting and creasing operation, the individual carton is cut from the board, and creases are added to aid the folding of the blank which forms the carton. Perforations are also cut at this point.

Cutting and creasing is said to have been originated in the 1870's after a type rule was set too high [Baldwin 1972]. Much development has occurred since then. The main systems are flatbed, flatbed/cylinder and rotary. The flatbed type of cutting and creasing operation is to be considered because of its flexibilty. The upper Platen of the platen press is composed of a matrix of cutting knives and creasing rules set in a wooden forme . The lower platen (makeready), has a corresponding matrix of channels. in the operation, a board will be drawn between the two. The platens will then be pressed together. In doing so the cutting rules cut through the board and the creasing rules force the board into the corresponding grooves, Perforating is part of the cutting operation. The waste material is stripped away, either on the machine, or manually off the machine. The final stage will be folding and erecting. Perforations have a wide range of applications and in the case of retail packaging, particularly where the package serves also as the dispenser, the perforations must ensure a clean tear. Untidy failure can lead to a poor perception of the package, which may reflect on the product.

## PERFORATION QUALITY ASSESSMENT

Properties of the board and the associated tests are listed in many sources [e.g. Kline 1983. Higham 1971]. Some of the tests relate to basic board properties, while others are concerned with their suitability for the conversion process, and subsequent performance, once in a different form. Stiffness has been described as a very important property [Fellers, Carlsson 1983, Hine 1963]. It is suggested that in reality, board is actually bought at so much stiffness per £ [Higham 1971]. The reason for its importance is that the effectiveness of a package to protect and contain is dependant on this property. Plybond strength affects stiffness and the compressive loading, but is more complex with respect to creasing, printing and perforating. Too high a plybond strength can cause poor creasing. After the crease has been made, a certain degree of delamination must occur during folding to ensure a good crease . There must be an upper limit to plybond strength. Printing may suffer due to insufficient plybond strength. Plybond is important for gluing, the strength of this sort of fixing being dependent on the strength between plies.

None of the above tests relate specifically to the perforation of the board. Taking a closer look, the perforations must fulfil two criteria. They must ensure that the material is sufficiently weakened so that tearing will occur along the desired line, but they must be strong enough to stay intact until they are purposely torn. In the case of a carton therefore, the perforation must survive the erecting, filling, sealing and transport of the box . Therefore the two requirements must be balanced in perforation design. The perforating rule used in the cutting and creasing operation consists of a length of rule with teeth. On cutting therefore, a series of incisions are made. The size and density of the incisions are obviously dictated by the design of the perforating rule. The size of incision and its density will control the amount the tear strength is reduced. There is, a discussion in Patent sec.1589127 (1977] concerning the design of perforations for a milk carton. The line of perforations have been evaluated for the effect of the ratio of incision size to uncut gap. As expected the results, shown in figure 1, showed that the greater the incision size relative to the gap, the lower the tearing resistance. Less obviously it was shown that tear resistance was higher the smaller the gaps between incisions, while the ratio of incision length to gap length remained the same (figure 1). The lines can be approximated by the formula:

$$\frac{\mathrm{TEAR_{CUT}}}{\mathrm{TEAR}}\ \alpha\ \frac{\mathrm{UNCUT\ LENGTH}}{\mathrm{TOTAL\ LENGTH}}$$

A novel cutting device is described in Patent Specification 1592 857. It is suggested that modern pin technology be used to produce the cut. If this technique were successful most of the problems outlined below would be overcome. The original difficulty of this approach was that it was possible to lose pins in the product, however, the patentees point out that in the manufacture of modern pin devices this problem has been overcome.

Direct testing of perforations has received less attention than other properties of packaging. Little other work appears have to been done to quantify the factors controlling perforation effectiveness. Tests that might be directly relevant to perforating are discussed below.

Tear appears to be important. The behaviour of paper using the standard test procedure is relevant to the observation of an unsatisfactory failure at a perforated line. The tear fracture mode is a complex function of fibre length and bonding. For hardwood pulps the tear curve passes through a maximum with beating, but for softwoods this maximum may not be found. In figure 2 illustrating the tear behaviour of softwood fibres [Ryder 1993] the relationship between tear and bonding goes through a distinct maximum for an essentially unbeaten pulp. A very gentle beating action resulting in a sharp drop in the tear index.This experiment agrees with the concept that maximum tear occurs with partial bond failure. From the theoretical point of view fracture mechanics, [ cf Helle 1987] could be invoked to study the mode of failure of paper and board. For this investigation the study of out-of-plane tear is needed ie the failure mechanism in three dimensions has to be studied.

Certainly there is no standard test to evaluate the 'quality', (in itself an ill-defined concept), of perforations. However a small amount of development has been undertaken. Papier- & Kunst-Verarbeitung [1980] describes a testing device developed to choose the optimum perforations for a paper type. This consists of two parts. the first a sample perforator with interchangable blades. the second, a special bending stiffness tester. It would seem that this offers one of the few purpose built methods of perforation evaluation. Hine [1970], mentions that the Albert and Concora tear tester can be used for testing perforated lines. The main drawback with this is that it appears suitable only for short, straight lengths of perforations. Within the area of tissue boxes the perforated lines are very often curved, and are not ideally suited to this sort of test.
In practice a test would be agreed between customer and supplier to ensure that the perforations match the required standard. This test must have a number of components. These would include a visual inspection of the perforations and the opening of the carton under prescribed conditions. The final aim would be to achieve a standard according to BS 5750 or ISO 9000.

## EXPERIMENTAL RESULTS AND PROCEDURES

The two distinct types of board a coated waste based board with that of a coated board made from virgin pulps are compared. The use of recycled board is increasingly popular, firstly because it may be cheaper, and secondly because of consumer demand for a 'greener' product. The differing materials and methods of manufacture can produce significantly different properties. In this study therefore, a white line chip (WLC) has been compared with a folding boxboard (FBB) to assess relative performances Table 1 shows a comparison of the basic board properties.

| | WLC | FBB |
|---|---|---|
| GRAMMAGE ($g/m^2$) | 259 | 277 |
| THICKNESS (m) | 500 | 500 |
| APPARENT DENSITY ($g/m^3$) | 518 | 554 |
| COAT WT. ($g/m^2$) | 19 | 18 |
| NO. OF PLIES | 9 | 5 |

**Table 1 BASIC BOARD PROPERTIES**

The recycled board was a cylinder formed board, while the folding boxboard was manufactured on a Fourdrinier/Bel Bond arrangement.

## 1. PHYSICAL TESTING

A number of physical tests were carried out on both board types. As well as giving a general comparison of some of the board properties, each test was chosen for one or more of three reasons:

i) It replicated forces involved during perforation cutting
ii) It replicated forces involved during opening
iii) It offered a possible test for the perforation quality

With these criteria in mind, the following tests were performed.

Tensile strength............... T 494 om-88
Tear strength................... T 489 om-86, T 496 su-72
Internal Bond Strength.... Scott I.B. Tester
Bending stiffness............ T 535 cm-85
Punch.............................. A non standard punch test developed within Department of Paper Science for brittleness measurment.

### Sample Testing

Samples were tested using the Elmendorf tear tester. No initial split was cut in the sample so that the maximum length of perforated sample could be torn. The results of interest were not the numerical results, but the visual. They were therefore recorded as failure by tear or failure by tear/delamination and an estimate of the extent of delamination was made.

## RESULTS

The results of the physical tests are shown in table 2.

| | | WLC | | FBB | |
|---|---|---|---|---|---|
| | | M.D. | C.D. | M.D. | C.D. |
| TENSILE INDEX ($Nmg^{-1}$) | Mean | 70.4 | 20.9 | 45.2 | 23.9 |
| | s.d. | 1.7 | 0.8 | 1.3 | 0.6 |
| BENDING STIFFNESS (mNm) | Mean | 59.3 | 18.2 | 45.7 | 19.5 |
| | s.d. | 5.3 | 0.8 | 1.4 | 1.7 |
| PLYBOND STRENGTH ($10^{-3}$kgm) | Mean | 11.4 | 11.8 | 9.22 | 9.47 |
| | s.d. | 1.10 | 0.90 | 1.22 | 1.62 |
| TEAR STRENGTH (Nm) | Mean | 206 | 230 | 151 | 170 |
| | s.d. | 32.7 | 6.2 | 22.2 | 3.6 |
| PUNCH FORCE (N) | Mean | 26.4 | | 21.9 | |
| | s.d. | 1.7 | | 1.7 | |

Table 2 RESULTS OF PHYSICAL TESTING

In industry the burst test is very popular, but Kleinert [1968] showed that there is no relationship between burst and the tear properties of interest.

In order to evaluate the effect of perforating the board on physical properties, a number of samples were cut from perforated blanks, and their properties compared to unperforated samples.

## 2. SAMPLE PERFORATIONS

### Cutting forme and sample cutting

A pilot cutting forme was obtained designed and constructed. This consisted of a matrix of cutting and perforating rules, laid out as shown in fig.3. The sample sizes produced were ones that could be used in the Elmendorf Tear Tester and Scott Plybond tester. The size of the cutting forme was determined by the dimensions of a laboratory screw press. Subsequent experimentation however, found this to provide insufficient pressure the fully penetrate the board. Hence a floor mounted Instron Universal Testing machine was adapted for use. The final cutting assembly is also shown in Fig 4. The compression plate of the Instron was a smaller area than the forme, so a plate was used to spread the load. Minor variations in pressure across the plate meant that cutting depth varied from one sample to another. This in turn meant that a range of sample depths were produced from one pressing.

### Perforation Classification (Fig 5)

For ease of identification, samples were given an arbitrary visual assessment as good, fair and bad according to the following criteria:

**G**, (good) - Perforations visible on reverse side of board, strong daylight visible through perforations.

**F**, (fair) - Perforations visible on reverse side of board, no daylight visible through perforations.

**B**, (bad) - Perforations faint or not visible on reverse side of board

The tensile strength is one of a number of tests that indicates the magnitude of anisotropy existing, particularly in the WLC, and to a lesser extent in the FBB. Such differences in properties between machine and cross direction must have significance in the later conversion of the board.

The punch force required to penetrate the board is higher for the WLC than of the FBB. while it is hard to accurately relate the value obtained above to the actual cutting process, it may imply a more rapid deterioration in rule quality.

Within packaging, the bending stiffness is of great importance both during processing and when fabricated into a package. For this study, however, bending stiffness was used to compare perforated and unperforated samples, to establish whether a significant drop in stiffness could be detected, and if so whether it might form the basis of a technique to examine good and bad perforations. The result was both surprising and disappointing. As table 3 shows, no significant difference could be detected between the perforated and unperforated board.

| | | |
|---|---|---|
| | **unperforated** | **perforated** |
| **mean** | **54** | **57** |
| **s.d.** | **5.3** | **12.5** |

**Table 3 COMPARISON OF STIFFNESS (mNm)**

## TEAR TESTING OF PERFORATED SAMPLES

As discussed above the tear test seemed relevant. High tear values agreed qualitatively with poor performance. This was because a high tear value usually implied delamination.

### 1. Fresh Rules

#### a) FBB

The folding boxboard samples cut with fresh rules were mainly influenced by depth of cut with respect to the mode of failure. All the samples that fell in the G category, i.e. light visible through the perforations, failed along the perforation line with no evidence of delamination. A similar result was obtained with the samples that were graded F. All samples that fell into the B category exhibited both tear and delamination in failure.

#### b) WLC

In a similar way to the FBB, samples that were graded G invariably failed in tear with no delamination occurring. Samples that fell in the F category however, were found to be more sensitive, with a percentage of samples exhibiting delamination. The percentage of the samples failing this way was higher for the CD than for the MD. All samples that were graded B, either exhibited delamination or, in the case of a number of cross directional samples, did not tear at all. The WLC exhibited a greater tendency to delaminate than the FBB.

### 2. Worn Rules

#### a) FBB

The result of using worn rules was to make the visual grading less reliable. Samples that were graded F could no longer be guaranteed to fail in the desired manner. More specifically, a percentage of samples that were cut cross-directionally exhibited delamination, while the M.D. samples again failed by tear only.

#### b) WLC

The use of worn rules with the WLC meant that the percentage of samples failing in tear/delamination increased ( class F ). Again samples cut with worn rules in the machine direction began to exhibit delamination.

The tendency of the WLC to exhibit large amounts of delamination on failure suggested a high tear/plybond ratio, such that delamination was the preferred path of failure. As can be seen from the physical test results, both tear and plybond results are higher for the WLC compared to the FBB. However the ratio of the two properties is the important factor. This ratio appears to be higher for the WLC than for the FBB.

## 2. MICROSCOPIC EXAMINATION

Micrographs were taken of a number of different perforation samples demonstrating the structure of the different grades. This was carried out using a Zeiss Laboval 4 microscope with a 35mm camera attachment.

Fig. 6 shows a perforation of the class G, from the reverse side of the board with transmitted light only. The perforation is seen to be a thin slit, and the depth of cut allows a lot of light through the board. The rule has made a complete cut, and no fibre remains. Fig. 7 shows a perforation from the classification F. Here the depth of cut is less which can be seen from the layer of fibres covering the slit. The amount of light penetrating the perforations has been reduced.

At the level of lighting used for figures 6 and 7 no light at all would penetrate sample classified as B. To be able to see a ranking of all three classifications(G, F and B), figures 8-10 have been produced with a higher light intensity. These three figures clearly show the reduction in the penetration of light as a result of the reduced depth of cut.

Figures 11-14 are examples of perforations cut with aged rules giving a classification of G and F. Figures 11 and 12 were produced at the lower light setting. The last two figures being produced at the higher light setting. The worn rules produce a wider slit and the depth of cut appears to be consistently less than that obtained with fresh rules.

## DISCUSSION

It can be seen from the results that a number of factors influenced the failure mechanism of a line of perforations. Significant among these were the board type and direction, particularly with a cylinder formed WLC board, which exhibited greater directionality. The higher tear resistance of the WLC, particularly in the cross direction (probably due to fibre orientation) meant that deeper perforations were required to ensure sufficient weakening of the board. This was more so for those orientated in the cross direction, which had the higher tear strength of the two directions. Also a rudimentary examination of the area delaminated showed that the WLC exhibited, on average, higher amounts than the FBB.

The photomicrographs indicated the depth and shape of cut obtained with each blade and from these the type of failure could be partly inferred. The perforations cut with fresh rules showed clean, narrow slits. The perforations cut with the worn rules were, not surprisingly, wider and less well defined. Hence the easiest path of failure would not necessarily be in the direction of the perforated line . Once tearing has been initiated, if the path is not along the perforated line, the force required for tearing may rise above that of the plybond strength. This being the easier path of failure would then would also be the preferential one. Combined with insufficient cut depth, the likelihood of delamination is increased.

## CONCLUSIONS

The effect of the pronounced directionality in the WLC has been demonstrated with regards to the perforation performance. The results have also indicated that plybond/tear ratio is significant in the mode of failure. The usefulness of transmitted light coupled with magnification has shown with respect to the examination of perforations for quality control purposes. This holds possibilities within QC as a method of assessment.

## ACKNOWLEDGEMENTS

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Ryder D J PhD Thesis UMIST 1993

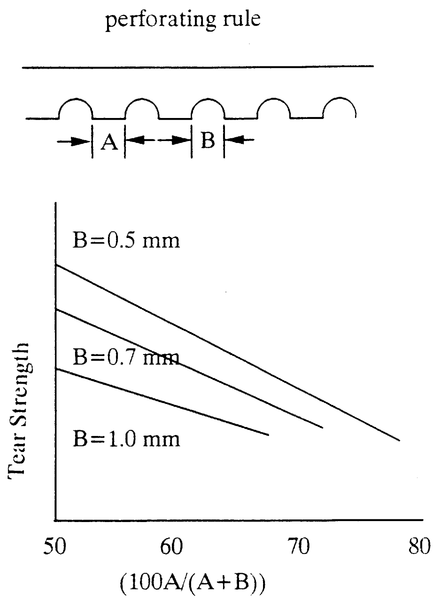
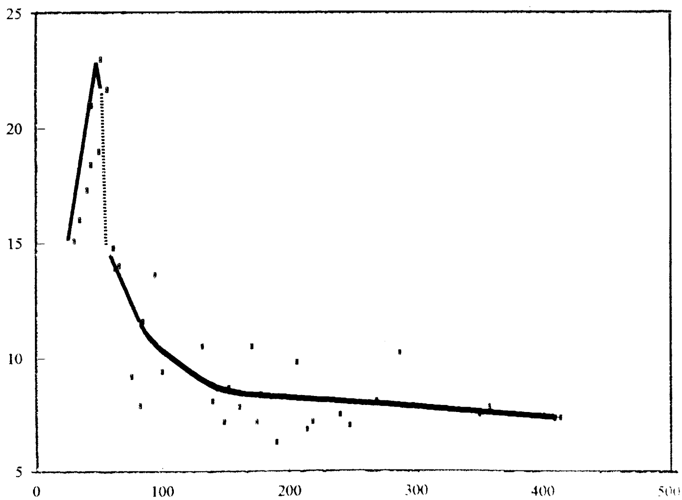



Fig 1 Perforating rule and tear strength

Fig 2 Tear Index vs Bonding Nm/g



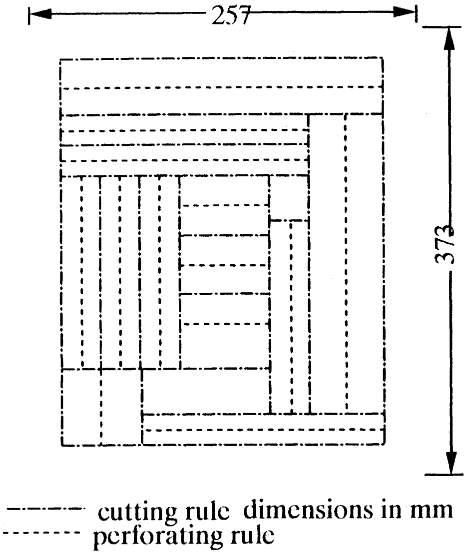
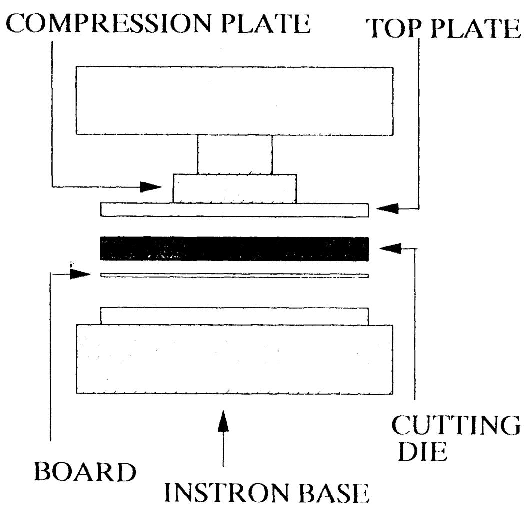



Fig 3 Plan of Pilot Cutting Forme

Fig 4 Laboratory Cutting and Perforating



| | | VIRGIN BOARD | | RECYCLED BOARD | | | |
|---|---|---|---|---|---|---|---|
| | | BOARD DIRECTION | | BOARD DIRECTION | | | |
| PERFORATION APPEARANCE | | M.D. | C.D. | M.D. | C.D. | | RULE CONDITION |
| | G | clean tear | | | | all | |
| | F | clean tear | clean tear | clean tear | possible delamination | Fresh | |
| | F | clean tear | possible delamination | possible delamination | possible delamination | Aged | |
| | B | delamination | | | | all | |
| | | M.D. | C.D. | M.D. | C.D. | | |
| | | BOARD DIRECTION | | BOARD DIRECTION | | | |

type of perforations { G-Good, F-Fair, B-Bad

Fig 5 Summary of Perforation Tear Performance

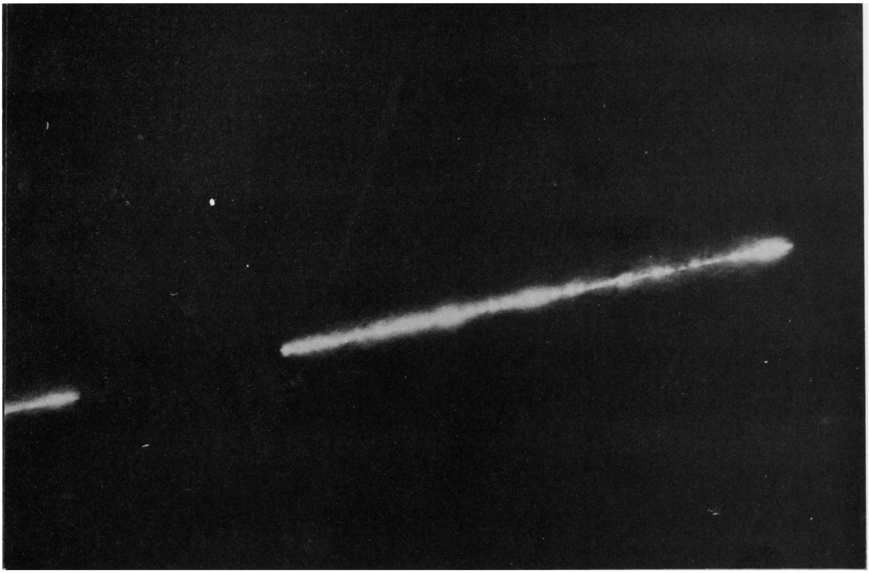


Fig 6    Fresh rule low light grade G

Fig 7    Fresh rule low light grade F

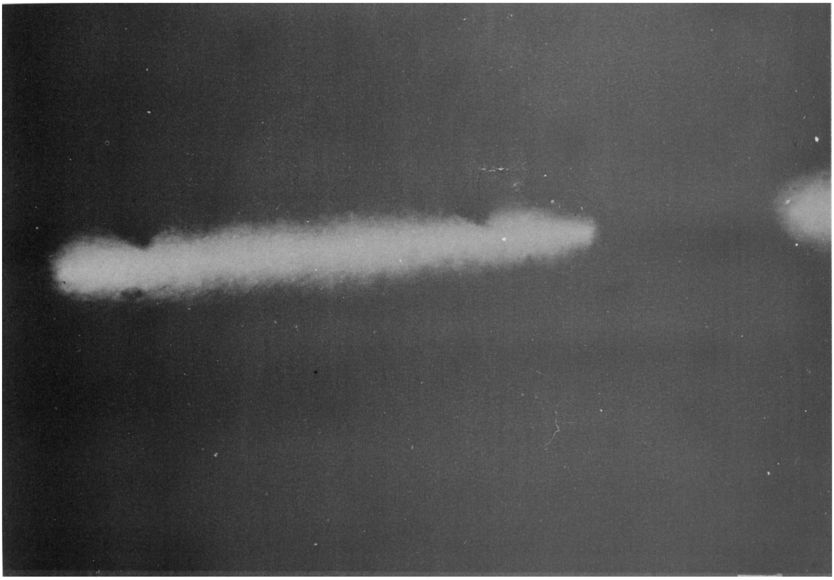


Fig 8 Fresh rule increased light grade G

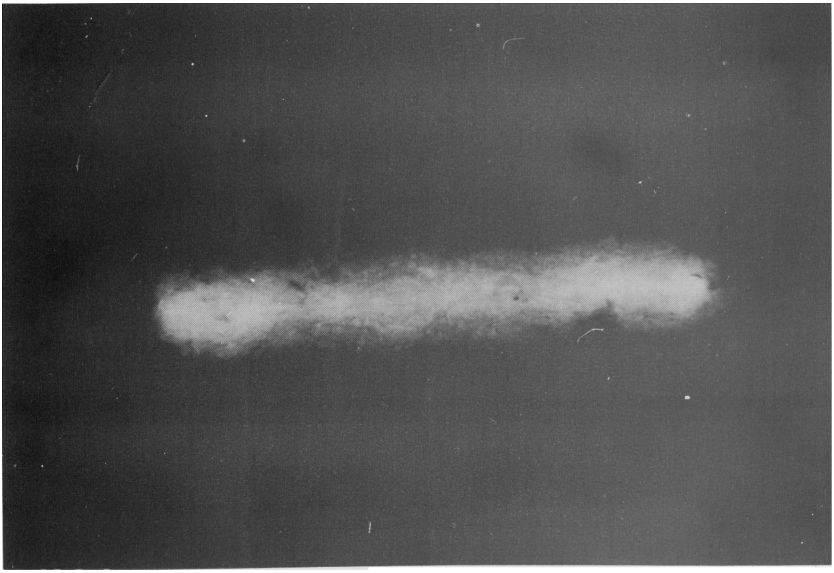


Fig 9 Fresh rule increased light grade F

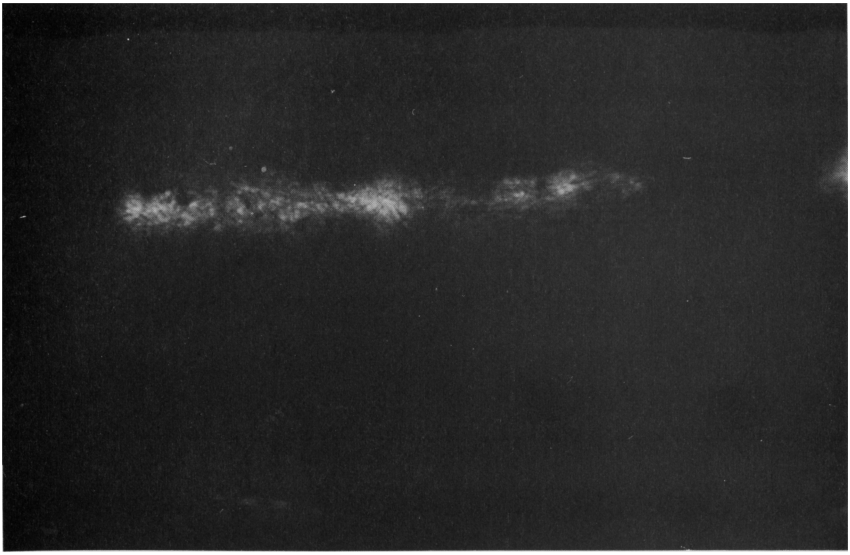


Fig 10  Fresh rule increased light grade B

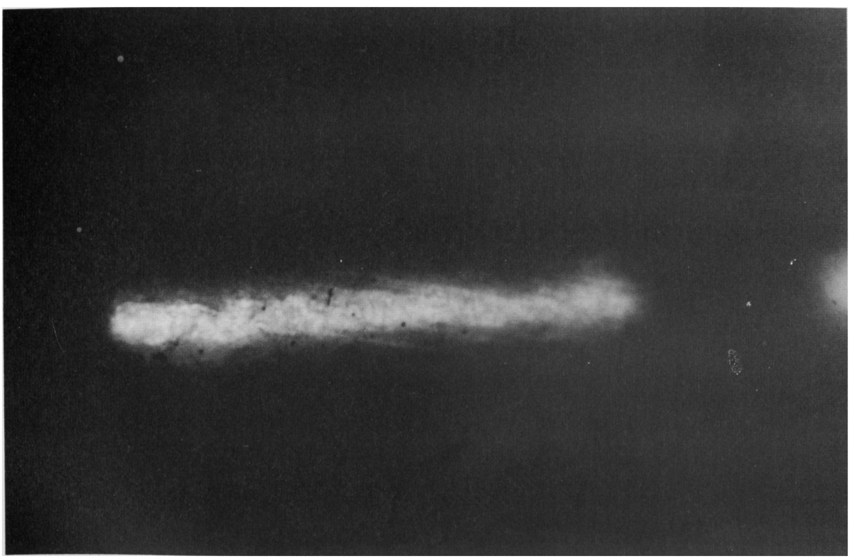


Fig 11  Aged rule low light grade G

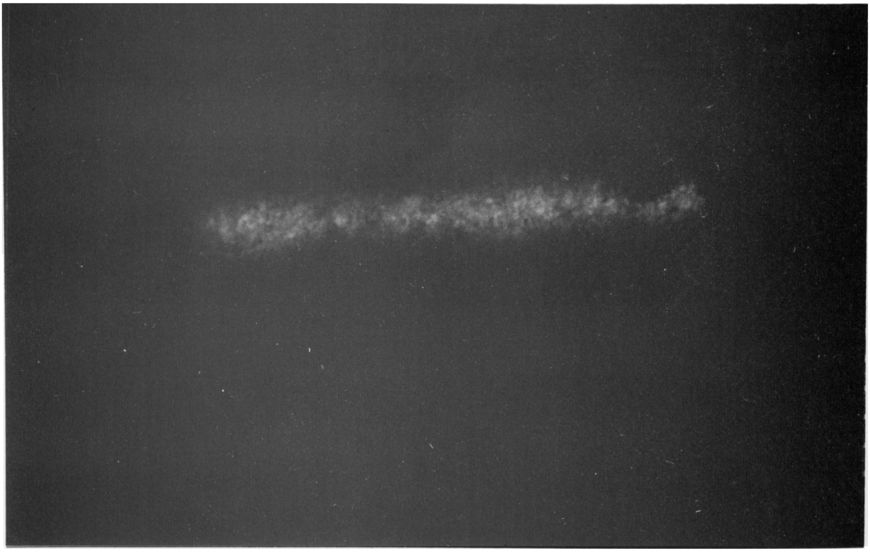


Fig 12  Aged rule low light grade F

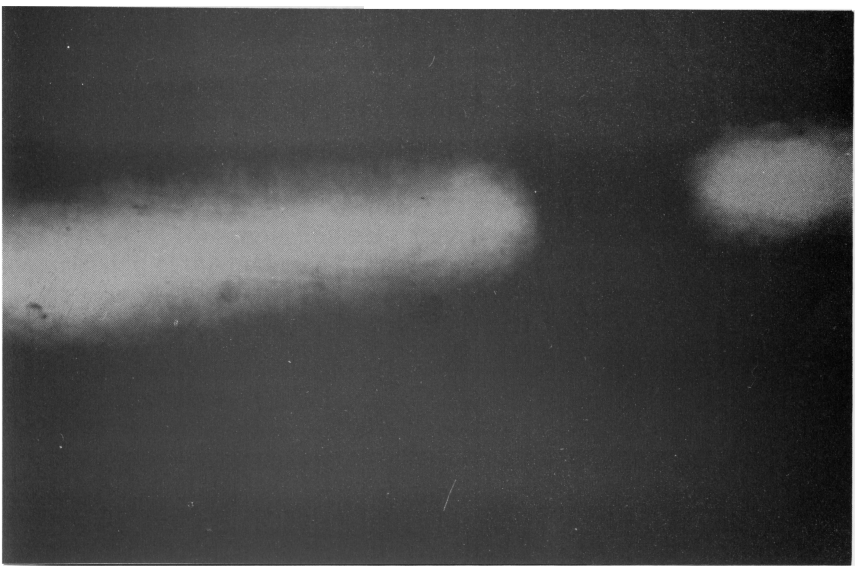


Fig 13  Aged rule increased light grade G

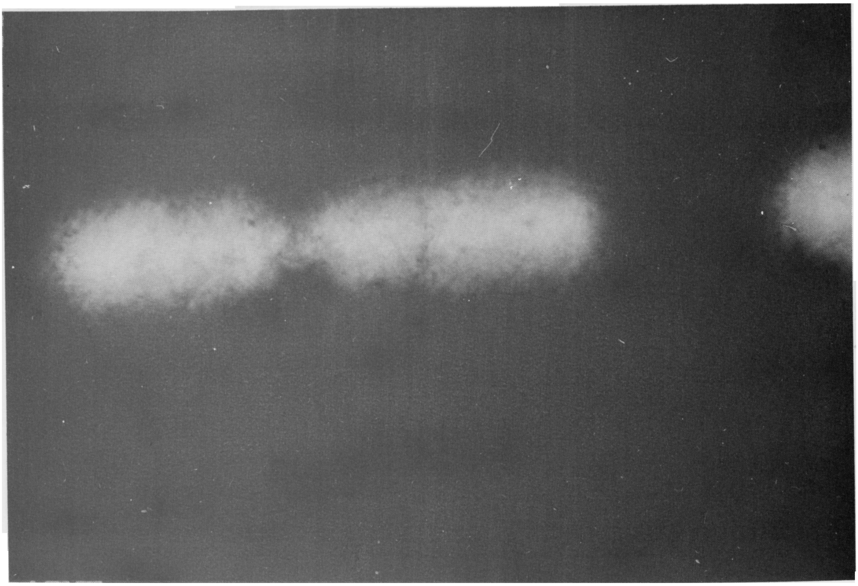


Fig 14  Aged rule increased light grade F

# Transcription of Discussion

## AN EVALUATION OF FACTORS AFFECTING PERFORATION QUALITY

H Kropholler

**Dr J D Peel, (formerly Kusters)**

Just a short question. You mentioned that directionality is important, is that connected to the fact that the tear design actually turns through 90º in the box. The actual perforation goes right from machine to cross direction.

**H Kropholler**

Yes, that is exactly it. It's a problem of the fibre alignment and that you tend to get fibres aligning roughly in the machine direction and so it is the cross direction tear that is more of a problem than the machine direction tear.

**Dr K Ebeling, Kymmene Corp, Finland**

Do you have experience about the layered structure and if the adhesion between the layers causes problems. Also have you any judgement on what type of boundary between the various layers in the multiply board would be most advantageous.

**H Kropholler**

The first bit first. Yes. The plybond and in fact Tim (Prior) found that what was quite important was the ratio of tear to plybond was quite good information to tell you whether you were likely to be in problems because when you have a bad tear you are getting plybond failure so you want a strong plybond. There is a slight snag as you can see from the pictures I showed here, that if you do any of the plybond tests you are failing at the weakest plybond. What you want to do is find the plybond that is near the bottom if you want to know how strong it is and not the weakest one in the structure so it is not so easy to pick the right one out but I think it is a very important factor in the nature of the failure. In fact it is quite an interesting aspect of fracture mechanics as to exactly where your failure is going to occur and of what nature. It is helpful that the classic Elmendorf tear test is the right type of failure for this sort of problem.