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DELAMINATION IN PLASTIC PACKAGES

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ABSTRACT

Delamination or the disbonding of the plastic moulding compound from various surfaces and interfaces in a packaged integrated circuit is a major cause of reliability failures. This paper reviews the causes of the said disbonding, the types of reliability failures that may be induced as well as various solutions available to prevent delamination.

INTRODUCTION

Delamination is defined as disbonding of two surfaces or the loss of adhesion at various interfaces. Recent developments in acoustic microscopy have allowed the non-destructive observation of such disbonding in plastic electronic packages as well as the correlation of defects including wire damage, thin film cracking and metal displacement to this phenomenon. These in-process and reliability failures were erroneously attributed to other root causes before. The direct observation of delamination and an understanding of its reliability implications have triggered efforts to further understand this phenomenon, the materials and process aspects resulting to delamination and the formulation of solutions.

Delamination presupposes the initial presence of adhesion. This adhesion comes from the chemical bonding between the molding compound and the various interfaces within the plastic package through highly specialized coupling agents added by the mold compound manufacturers to their molding compounds. The difference in the coefficients of thermal expansion (CTE) between the molding compound (CTE 20 ppm) and the silicon chip (CTE 6 ppm) also results into mechanical bonding between the compound and the chip as the package is cooled from the molding (175°C) down to room temperature.

Advances in acoustic microscopy have allowed the non-destructive detection and observation of delamination between the molding compound and the die/leadframe interfaces. The principle involved is the detection of deflected and reflected high frequency sound waves as they encounter discontinuities in a composite material. This technique is not exactly new and has been the basis of the well-known ultrasonic testing in the metals and welding industry. The advent of computer technology has allowed the imaging or generation of images in real time of these defects or discontinuities.

High resolution x-ray radiography is also used as a technique for non-destructive detection of delamination. The resolution of this method, however, is less sensitive compared to the acoustic microscope and will only allow imaging of gaps in the micron range.

Precision cross-sectioning is a destructive technique but is the only method of physically verifying a delamination. In the application of this technique, not only is the precise location of the cross-section important. So is the choice of the potting or mounting resin used. Quick dry and bakelite-based potting media can often apply sufficient stress upon setting to cause existing air gaps to close, revealing no delamination upon cross-sectioning. A slow cure epoxy is the recommended potting medium for this technique to work.

FAILURES INDUCED BY DELAMINATION

Wire necking and heel cracking (Figure 1) are common failures induced by delamination. These failures were previously attributed to poor wire bonding. An analysis of the tensile strain on the gold wire during thermal cycling show a tremendous effect of die surface delamination. In the absence of delamination, the strain on the gold wire may be estimated by the following equation:

$$\gamma_{Au} = (\alpha_p - \alpha_{Au}) \Delta T$$

where

γ_{Au} = strain on gold wire,
α_p = CTE's of plastic and gold,
α_{Au} = range of temperature.

For thermal cycling between 150 and - 65°C, and a difference in the CTE's of 7.7 ppm, a strain of 1,658 ppm is estimated. This value is below the strain of gold at the yield point of 2,000 ppm. No permanent deformation or damage on the wire is experienced.

In the presence of delamination, however, the tensile strain is estimated by the equation:

$$\frac{\gamma_{Au} = d(\alpha_p - \alpha_{Au})}{l}$$

where
d = 1/2 of the die length,
l = delamination gap.

For a 355 mil die and a delamination gap of 4 mils, a strain of 73,463 ppm is estimated. This value is way above the breaking strain of the wire. Bond cratering and ball lifting may also be induced by delamination. The stresses transmitted by a delamination interface can result in the cracking of the silicon under the bond pad metalization (see Figure 2). A rounded ball bond is also more susceptible to ball lifting when delamination occurs.

Corrosion (Figure 3) is an obvious reliability concern when such disbonding, specifically of the lead frame plastic interface extends to the external of the package. Such delamination would allow moisture and impurity ions to reach the die and induce corrosion.

Passivation cracking and metal displacement may also be induced by delamination (Figure 4). During thermal cycling, an undelaminated interface would expand and contract simultaneously and with the same magnitude. The presence of die surface delamination, however would allow the plastic to move with a larger amplitude and cause it to exert pressure on the passivation and the metallization, as shown in Figure 5.

MECHANISM OF DELAMINATION

Thermal mismatch, the same phenomenon which gave rise to mechanical bonding can also be the cause of disbonding when the package is subjected to thermal cycling. The maximum stress at an interface, σ_{max} may be estimated by the following equation:

$$\sigma_{max} = \Delta\alpha E \ \Delta T$$

where

$\Delta\alpha$ = difference in CTE's,
E = moduli of elasticity,
ΔT = range of temperature.

When this stress exceeds the chemical bonding strength, delamination will occur. This type of delamination is normally seen to start at the corners of the die and progressing to the die center with continued stressing.

Moisture has also been observed to impact delamination. Figure 6 shows an increase in the percent delamination as the moisture content of the package increases. A recent publication has revealed the degradation of the chemical bonding at interfaces in the presence of moisture. Figure 7 shows that in the absence of moisture, the plastic tends to crack through the epoxy resin. In the presence of moisture, however the fracture occurs at the filler-resin interface.

Various issues relating to assembly packaging can also result into an increased tendency towards delamination. Shifting of the die paddle and uneven filling of the top and bottom cavities of the mold die results in differential stress levels between the upper and lower sections of the package. These stresses may be sufficiently high to delaminate the package.

The presence of voids inside a package can also result into delamination. Internal voids act as stress raisers which could amplify the applied stress by as much as three (3) times. Internal cracking can be initiated by these voids which eventually propagate to the nearest interface and create delamination.

Mechanical stresses during ejection from the mold die, dejunk, trim and form can also create enough stress at various interfaces to cause delamination. packages with a centrally located ejection pin will show delamination at the center of the package if an ejection problem is present.

Aspects of the die attach process such as resin bleed, fillet height and improper curing impact delamination are observed as disbonding of the mold compound from the die paddle around the die. The adhesion of the mold compound to the die attach components is inherently weaker. Improper curing can cause the release of volatile material during molding which could open up interfaces.

The adhesion of the molding compound to cuprous oxide has been observed to be higher than to the metallic copper surface. Thus, the generation of the native oxide on the copper leadframe surface as it goes through the assembly process is highly beneficial. The same study has shown, however that an optimum oxide thickness of about 600 A exists (see Figure 8). Beyond this thickness, the stress at the oxide-metal interface is large enough to cause the "spalling" or disbonding of the oxide from the copper substrate. Thus, excessive oxidation should be avoided.

SOLUTIONS TO DELAMINATION

Reduction in the moisture uptake, together with a redesign of the coupling agent have been proposed as the major solution to delamination problems. Reduction in moisture uptake is obtained by increasing filler loading and the use of hydropholic resins. Figure 9 is a comparison of the moisture uptake of various types of molding compounds. The chart shows that the new biphenyl epoxy type resins exhibit the lowest moisture absorption, much lower than the conventional epoxy novolac.

Redesigning the leadframe can also improve the margin against delamination. The introduction of anchor holes and dimples create mechanical interlocks which help prevent disbonding of plastic-leadframe surfaces. Removal of the silver plating on the die paddle and its minimization on the lead finger areas have also been proposed as the adhesion to the bare leadframe is stronger than to the silver plating.

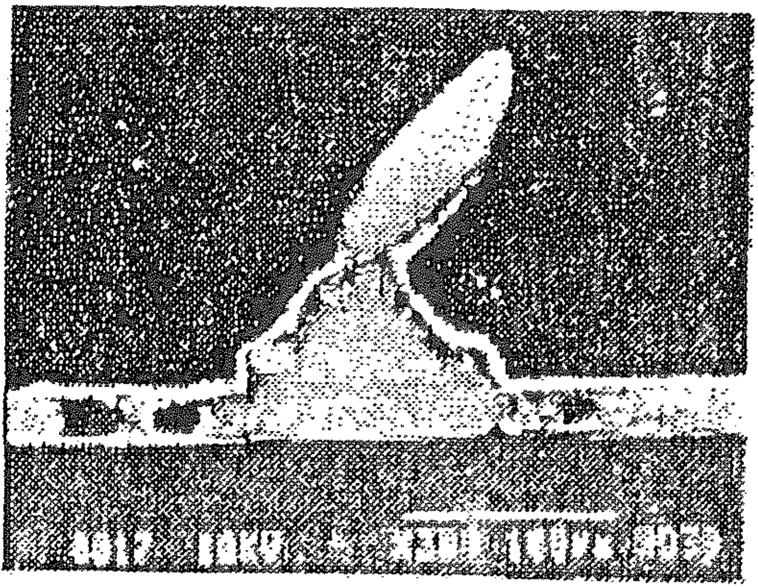
Improvements in assembly operations can definitely improve the margin against delamination. Even filling of the top and bottom cavities may be obtained by centering the die at the mold die parting line and adjusting mold die temperatures. This not only equalizes upper and lower section stresses but also minimizes internal voiding. Plunger velocity optimization and proper air vent design further reduces tendency towards internal voiding. Improved adhesion is also obtained at higher molding temperatures (T = 180-185°C) due to better fluidity of the molding compound as the temperature increases. Such a solution could, however, increase the tendency toward internal voiding and incomplete filling and thus should be managed very carefully.

Improvements in the die attach area include minimization of the fillet height, zero bleed out and complete curing. The use of low oxygen cure furnaces has not unilaterally resulted in better delamination performance in industry.

Die surface delamination is most critical as it causes wire necking and other failures as well as thin film cracking. Various die surface treatment techniques have been proposed to improve die surface adhesion and this include mold pre-bake to volatilize organic contaminants, die coating such as polymide and hexamethyldisilazene (HDMS) and plasma/chemical cleaning of the die prior to encapsulation. These techniques, however have not been widely accepted in industry.

CONCLUSIONS

Present day customers require integrated circuit packages that are robust with respect to delamination. Margins may be obtained through process optimizations at the die attach and mold areas. Additional margins may be obtained through leadframe redesigns but quantum leap improvements may only be obtained through the use of next generation biphenyl epoxy molding compounds.



Delamination-induced wire necking

Delamination-induced heel cracking

Figure 1.
Delamination induced wire necking and heel cracking.

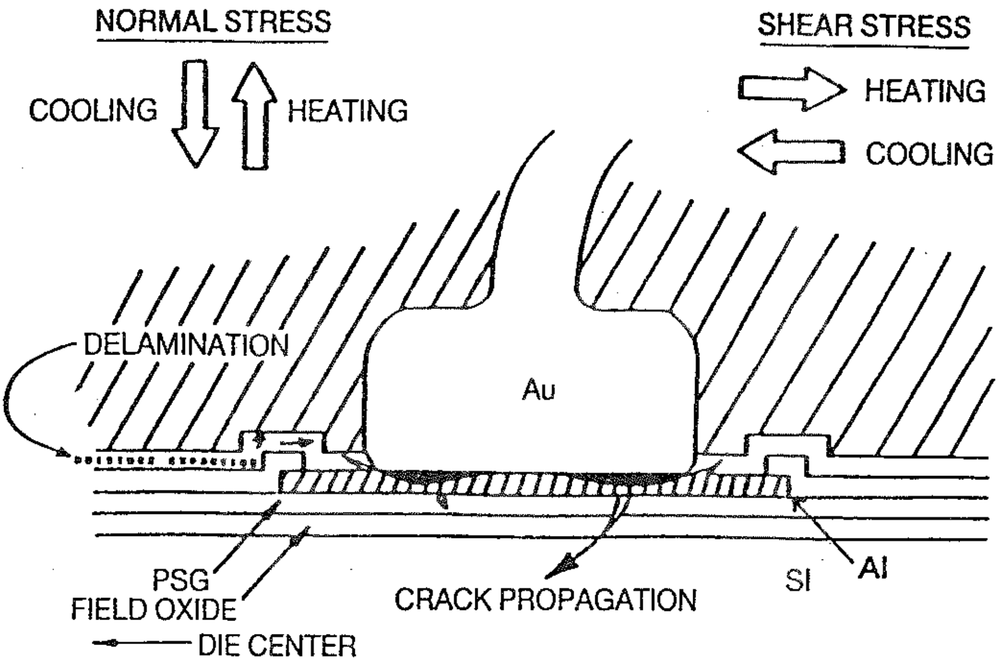


Figure 2.
Bond cratering and ball lifting mechanism.

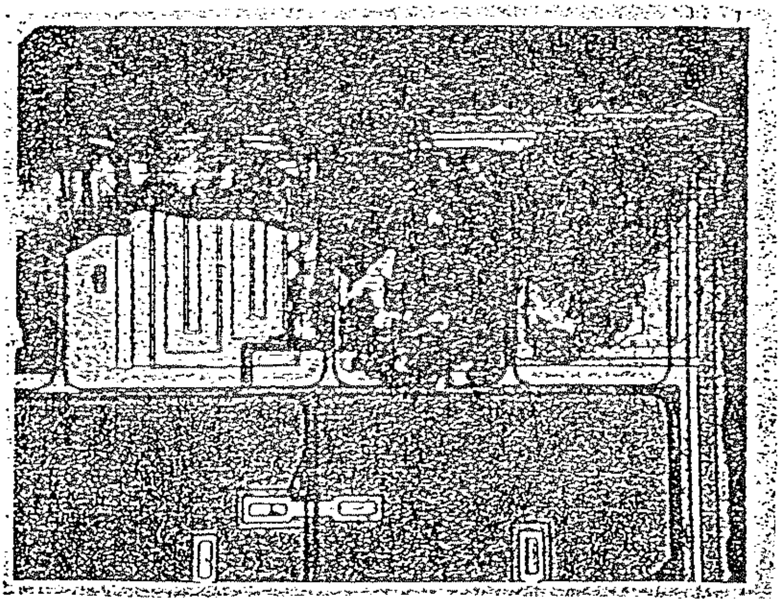


Figure 3.
Delamination induced metal corrosion.

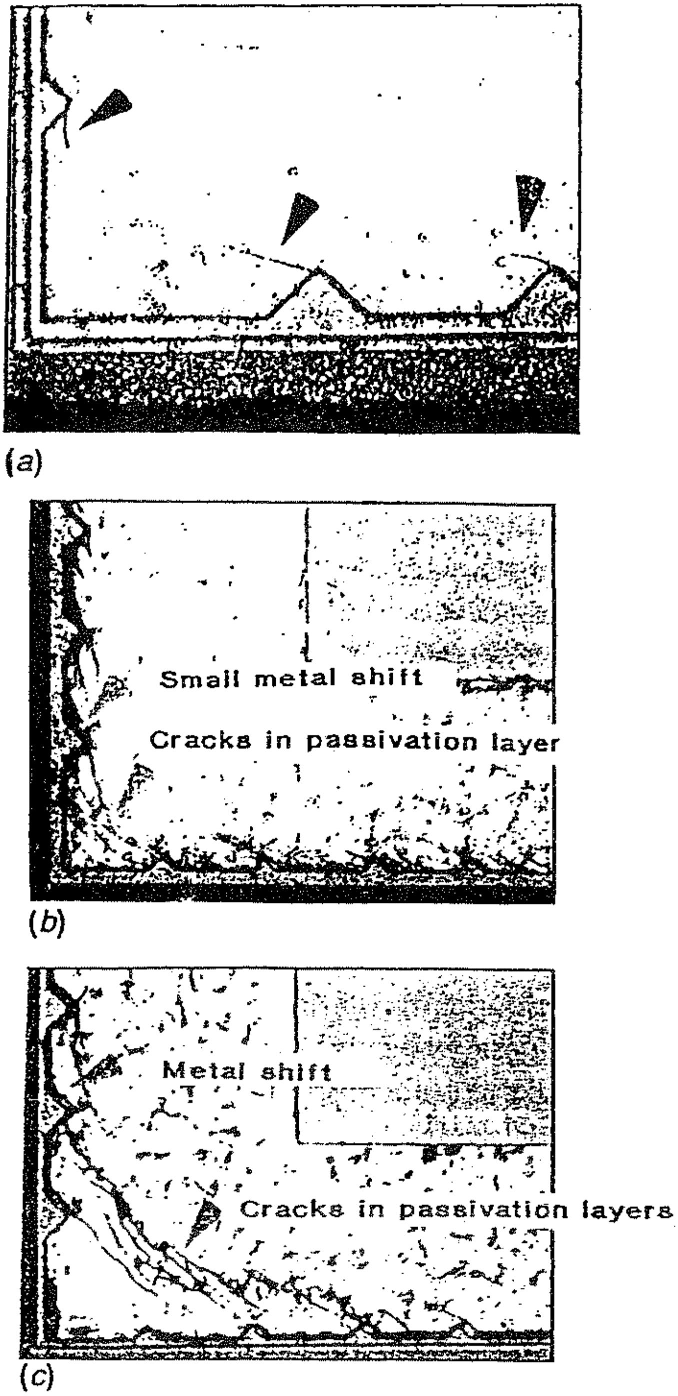


Figure 4.
Passivation cracking and mental shift at die corners after molding (a), after thermal cycles -55°C/150 (b), and after 200 thermal cycles -55°C/150°C (c).

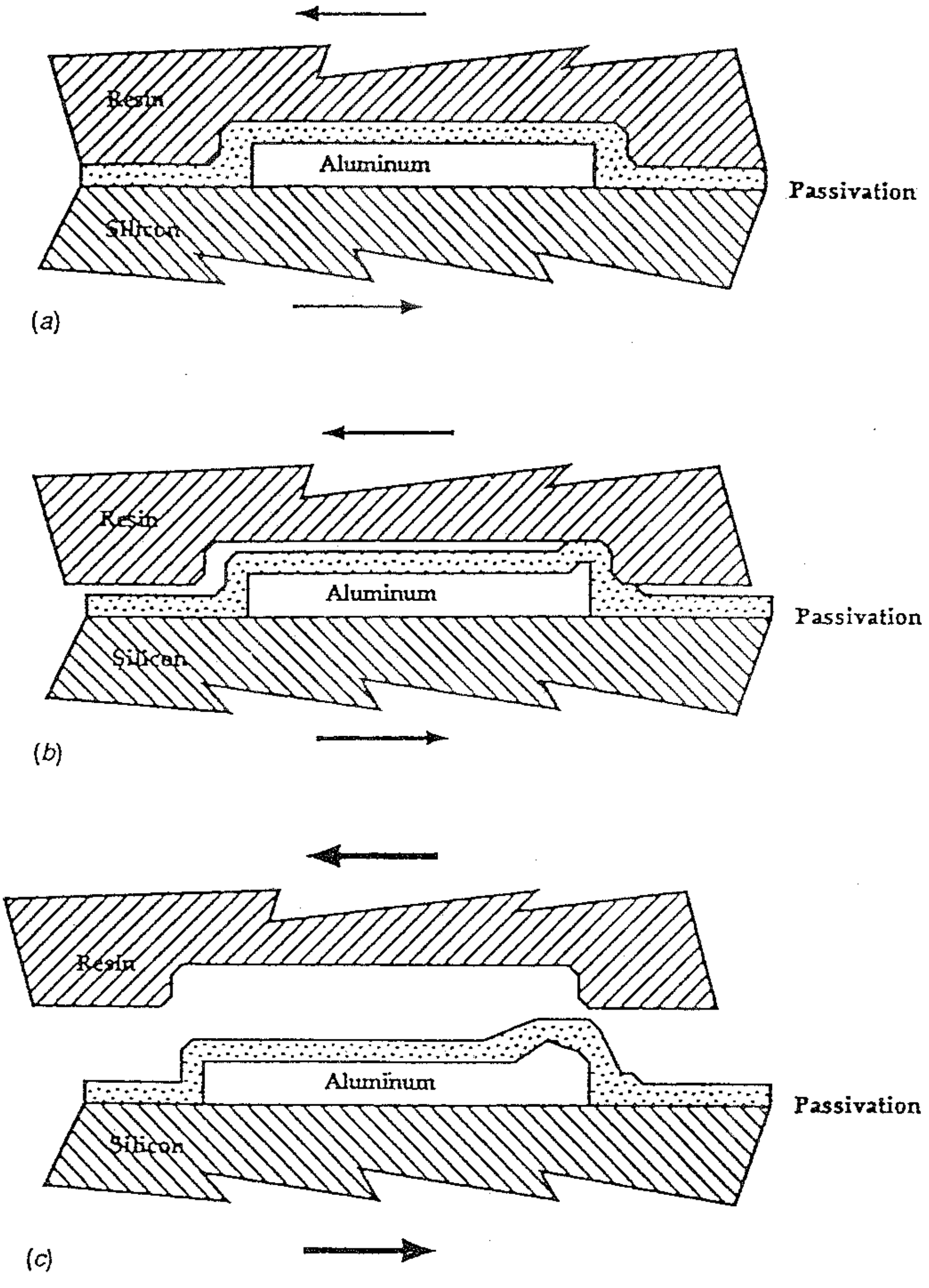


Figure 5.
Mechanism of pregressive delamination during thermal cycling, after molding (a), partial delamination (b), total delamination (c).

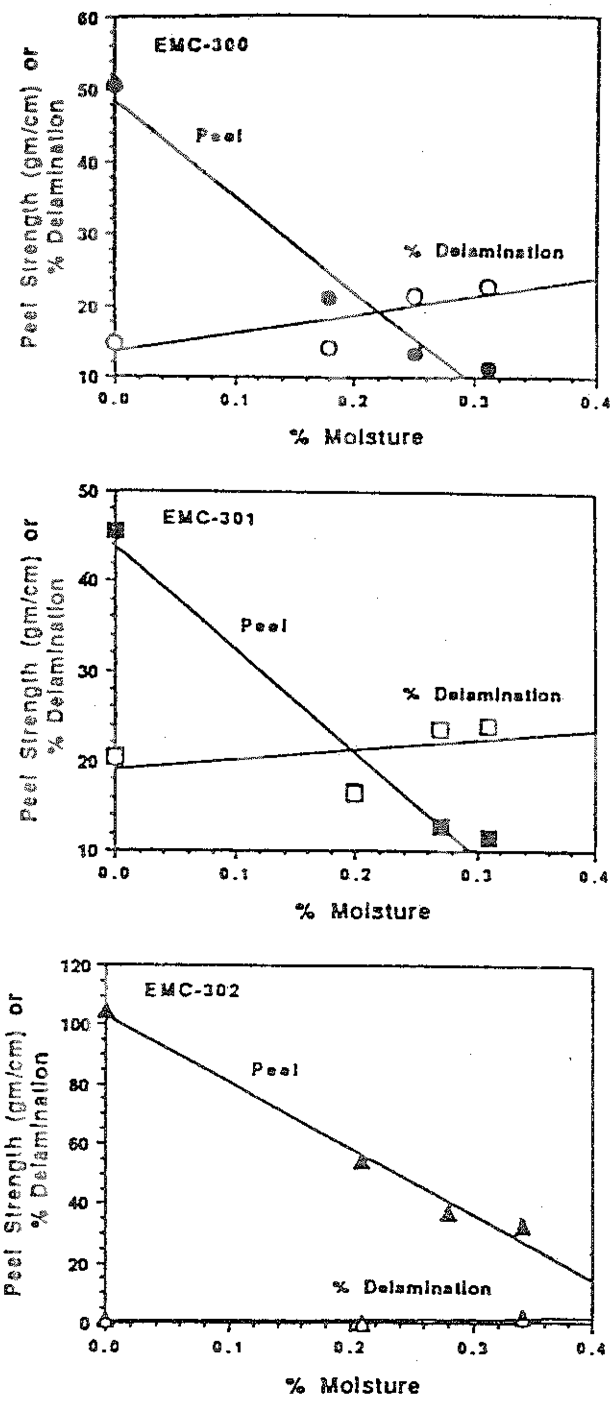
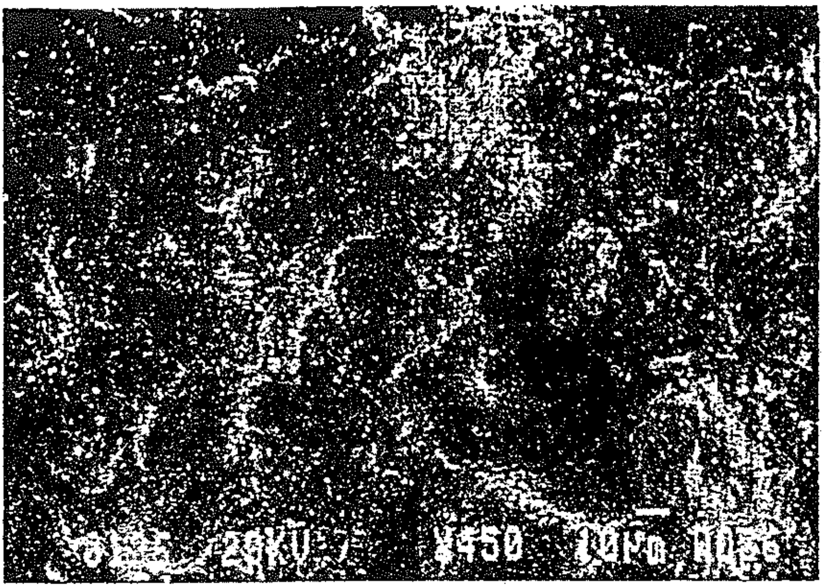
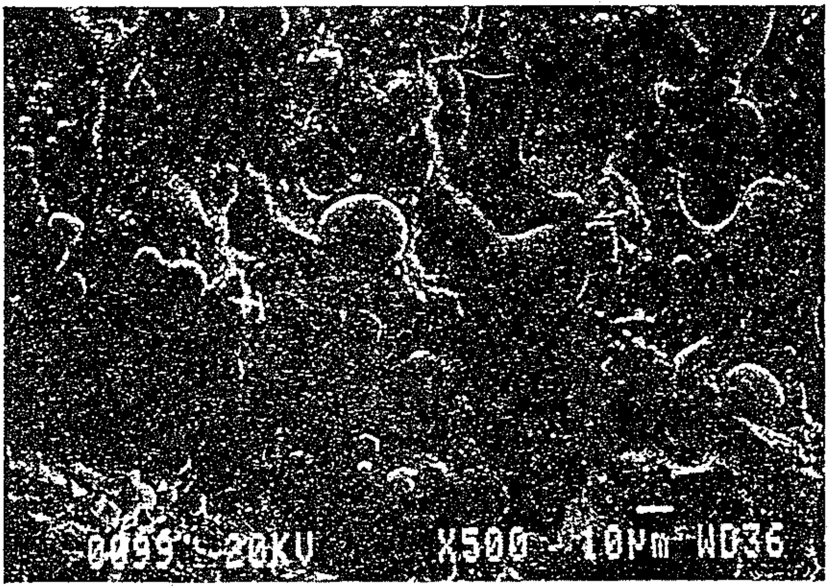


Figure 6.
Relationship between moisture adhesion strength or percentage delamination as a function of moisture content for three different molding compounds.



Test sample crack morphology (a)



PQFP crack morphology after moisture (b)

Figure 7.
Fracture surface of molding compound in the absence of moisture (a), and after moisture exposure (b).

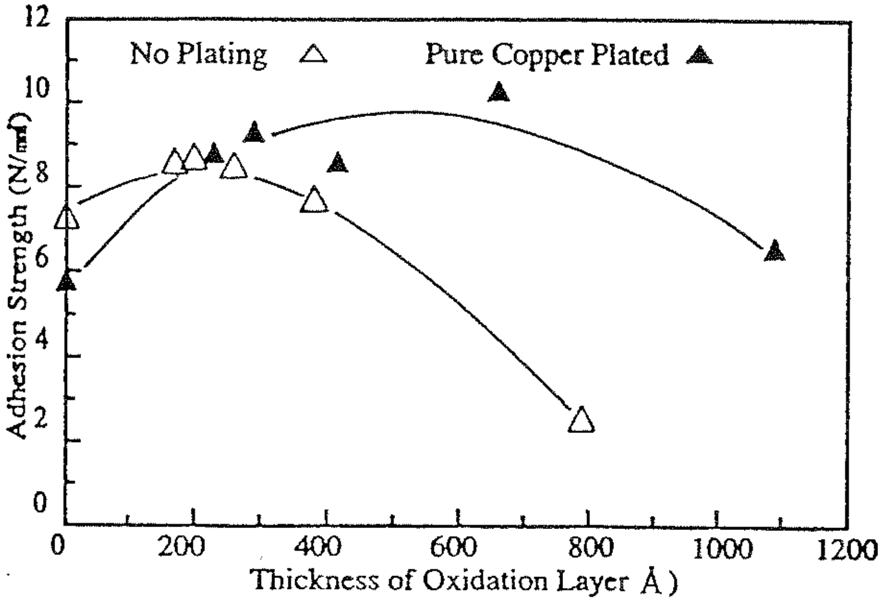


Figure 8.
Adhesion of molding compuond as function of native cuprous oxide thickness.

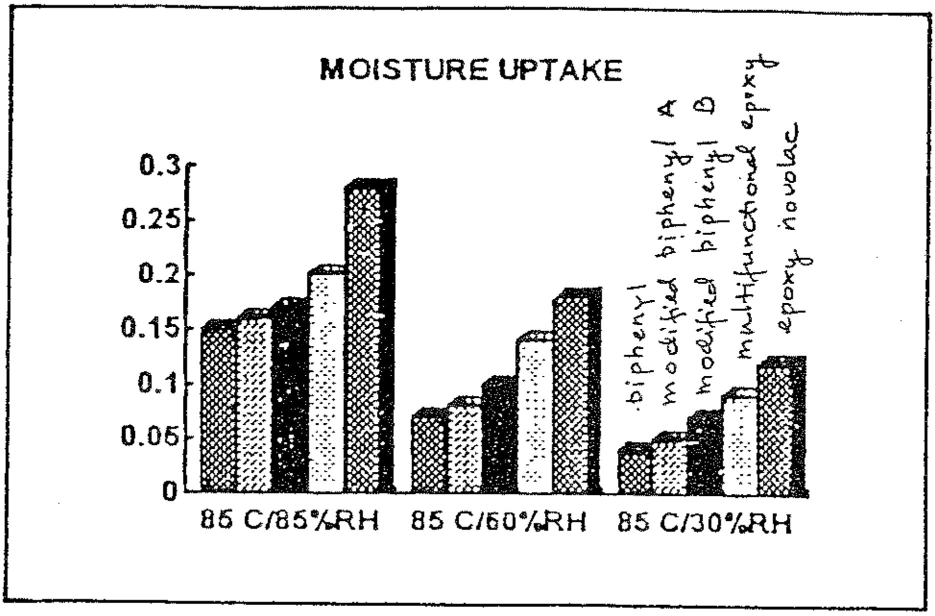


Figure 9.
Moisture uptake of various molding compound resins.