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TRYBOLOGICAL CHARACTERISTICS OF PRINTED CIRCUIT BOARDS DETERMINATE TROUGH MICRO-SCRATCH TEST

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The goal of the present paper is to describe some tribological aspects regarding the adhesion of the copper layer deposit on the rigid support of printed circuit boards (PCB) used in electronic technology. In order to highlight the adhesion of the copper layer in correlation with different rigid support, there were performed some micro-scratch tests using a dedicated system. The paper novelty presents a mechanical experiment which will describe the tribological properties with influence on the reliability of electronic assemblies.

Key words: micro-scratch, tribology, adhesion, cooper, printed circuit boards.

1. Introduction

One of the three functionalities of electronic assembly is the mechanical attachment. According to previous studies [1], [2], [3] the mechanical strength of the electronic solder joints depends on the pad finish, for example most brittle fracture were observed on silver immersion (ImmAg) pad finish, hot air levelling (HASL) finish showed a god stability on reflow soldering conditions and no brittle fracture were observed on NiAu finish.

Also in all the experiments was observed a detachment of copper layer from rigid support. Starting from the results presented above we decide to verify if the adhesion of the cooper layer depends on the material of rigid support.

The experiment is oriented on common electronic packaging materials since the aim of the work is to add knowledge in order to solve problems from electronics industry. As printed circuit board (PCB) there were used three well-known rigid supports: FR2 (synthetic resin bonded paper), FR4 (woven glass fabric with epoxy resin system) and CEM (Composite epoxy material).

There are several techniques known for adhesion and delamination testing, some of the most common being a tape test, stud-pull test, scratch test and an indentation test. The scratch (indentation) test, uses an indenter moved in both vertical (loading) and horizontal (sliding) directions, and an acoustic emission

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sensor that allows the detection of the initiation of fracture, while the scratch pattern indicates the type of failure. [4]

The Institute of Interconnecting and Packaging Electronic Circuits trough the IPC-TM-650 Test Manual Methods establishes uniform methods for testing electronic and electrical parts including basic environmental, physical and electrical tests. [5]

For some time, the accepted test method for measuring adhesion in the printed circuit boards industry has been the peel strength test. Yet it is accepted that this technique has been less than adequate in guarding against delamination failures during reflow and wave soldering. A recently introduced test method, now a part of IPC-TM-650, is the so-called "T260 Method" in which a thermal event is imposed that causes a delamination of the test specimen. The objective of this study is to compare the stress field associated with a board delamination to that generated by the peel and T260 tests.

Initial attention is given to a first principal characterization of the stress field associated with a uniform, free expansion of a printed circuit board (PCB), as in the reflow process. If severe enough, this will result in a delamination. The stress fields produced by the peel and T260 tests are then analysed and compared to that of a free expansion. Finally, a novel technique is suggested for performing this measurement. [6]

Adhesion test was made with the help of special equipment that performs scratches on the cooper surface and give as result the value of the friction force, normal force, penetration deepness and friction coefficient. The micro-scratch test is used for the characterization of adhesion failure of thin films or coatings with small thickness.

The micro – scratch test depends on measuring the amount of deformation caused when the indenter is pressed in to the surface with a fixed force.

The disadvantage is that that although hardness of material depends on the plastic properties, the stress-strain relation cannot be obtained. [7]

In the case of the present paper the experiment aims to determinate the adhesion of a cooper film on a rigid and non-conductive support. The thickness of the cooper foil in all three cases is about 75μm. Through this test we try to identify the cooper coating comportment on different rigid supports and the way that this comportment can influence the quality and reliability of the electronic assemblies.

2. Experiment description

For the experiment we used an UMT Micro-Scratch Equipment. The schematic of the setup used in this study is shown below. It can provide rotational translational or reciprocating motions with speeds ranging from 0.1 μm/s up to 10 m/s. The load is applied to the sample by the carriage using F_z for a close-loop feed-back mechanism for stability and accuracy and can be kept constant or linearly increasing from as low as 0.05 g to as high as 1000 N. Friction force (F_x), normal load (F_z), penetration deepness and friction coefficient are measured and recorded at a total sampling rate of 20k Hz. Wear depth electric capacitance and digital camera are also readily available. The configuration below is an example of one of many possible combinations of friction/load sensor lower drive specimen holder and specimens. [8]

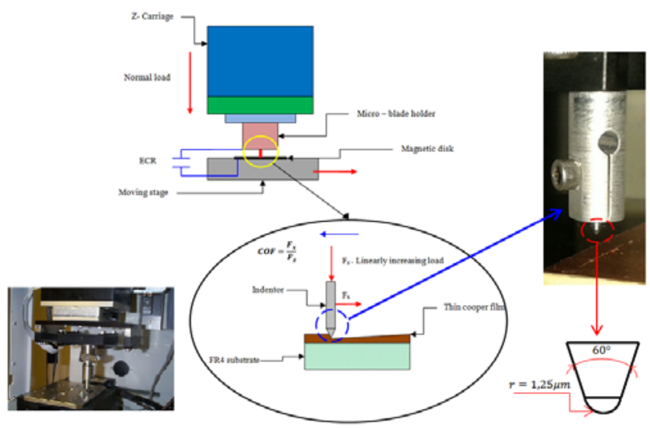


Fig. 1. Functional scheme for Micro-scratch test equipment

The experiment consists in a progressive scratch with a length of 20 mm, the indenter will move with a speed of 0.5 mm/s for 20 s, with a tolerance of 1 %. Scratch depth is 0.15 mm representing the double of Cu the layer thickness, deposited on rigid substrates. As an indenter we used a use a steel diamond cone with tip angle of 60 ° and a radius of 12.5 µm.

Test samples were cleaned with isopropyl alcohol for removing the oxides deposited on the surface of the copper layer, their appearance on the surface of circuit boards used in the experiment was inevitable because the cooper layer has no coating.

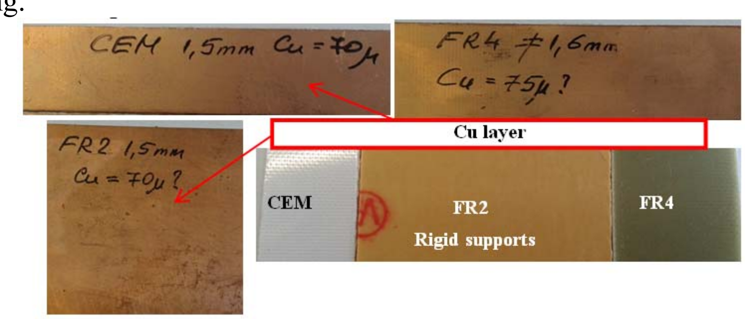


Fig. 2 Test samples

The sensor used has a value of 50 N and the test boards that were mounted on the equipment are shown in fig. 3.

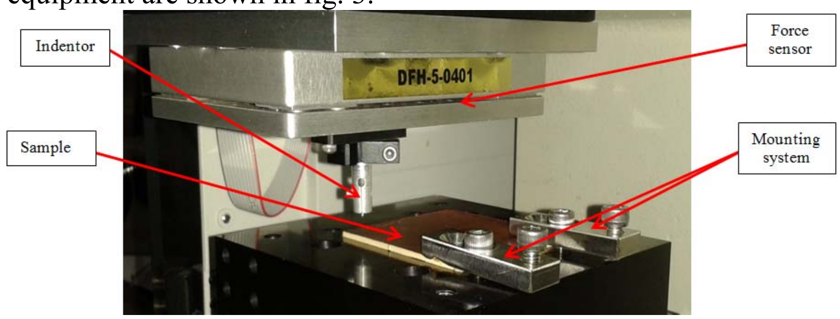


Fig. 3 Mounting system

The results are captured with the help of acquisition system they may be viewed, analyzed and interpreted by using the control unit.

After the micro-scratch test profilometry of the sample was determinate with the help of SJ301 (Mitutoyo, Japan) profilometer. Optical inspection was made with a video system Leica (Condor 70-3 – share test equipment).

3. Sample description

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate.

The most common substrates used in electronic technology are FR2, FR4 and CEM.

FR-2 is an abbreviation for Flame Resistant 2. It is composed from synthetic resin bonded paper, a composite material made of paper impregnated with a plasticized phenol formaldehyde resin, used in the manufacture of printed circuit boards. FR-2 sheet with copper foil lamination on one or both sides is widely used to build low-end consumer electronic equipment. It is not suitable for devices installed in vehicles, as continuous vibration can make cracks propagate, causing hairline fractures in copper circuit traces.

FR4 is a grade designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods and printed circuit boards (PCB). FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant (self-extinguishing).

The material is known to retain its high mechanical values and electrical insulating qualities in both dry and humid conditions. These attributes, along with good fabrication characteristics, lend utility to this grade for a wide variety of electrical and mechanical applications.

CEM is a composite epoxy material typically made of woven glass fabric surfaces and non-woven glass core combined with epoxy resin.

4. Results

On FR2 and FR4 sample there were performed 5 scratches. For every scratch we determinate the normal force, friction force and friction coefficient depending on the scratch depth that was imposed at 0.15 mm.

In figure 4, 5 and 6 is represented the variation of friction coefficient depending on the depth of the scratch for each sample FR2, FR4 and CEM.

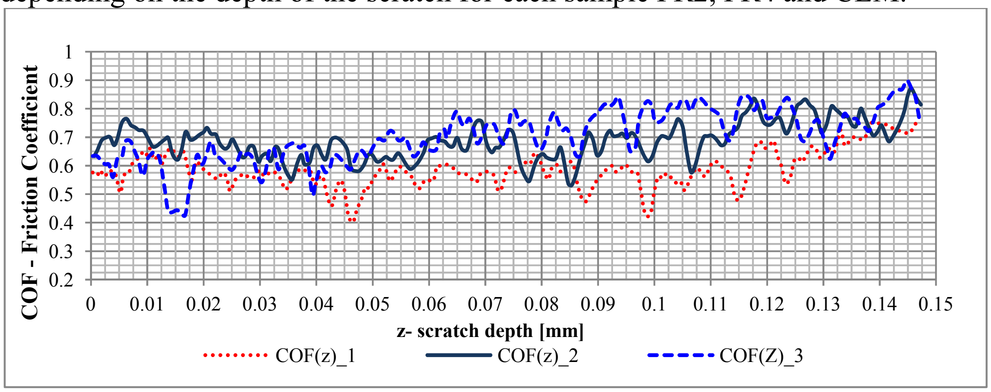


Fig. 4 Variation of friction coefficient depending on scratch depth for FR2 sample

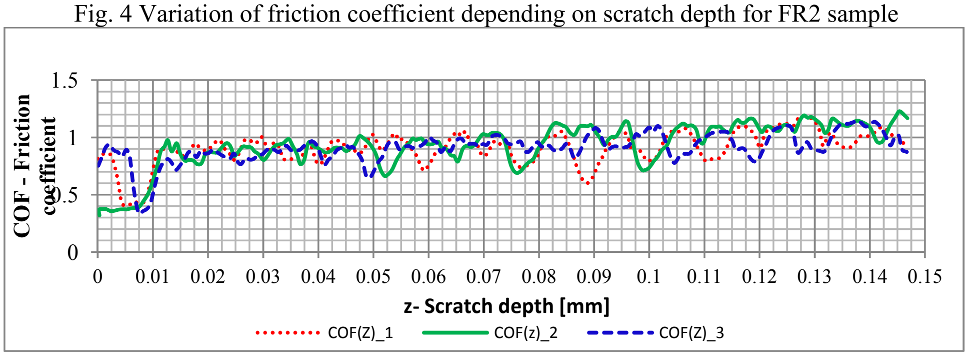


Fig. 5 Variation of friction coefficient depending on scratch depth for FR4 sample

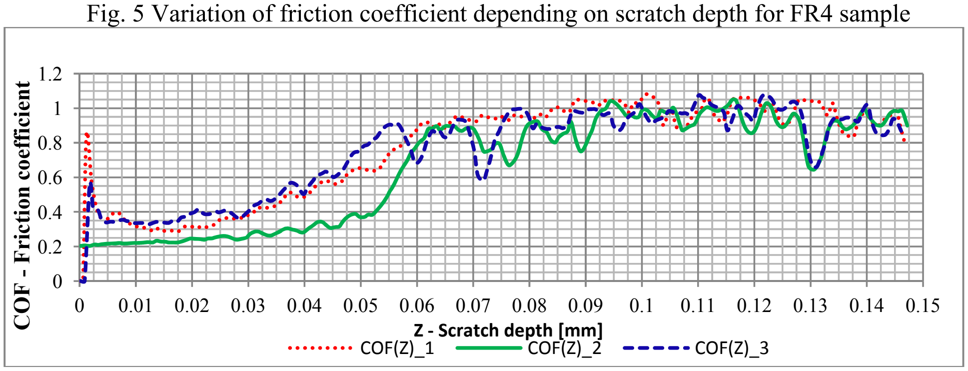


Fig. 6 Variation of friction coefficient depending on scratch depth for CEM sample

The variation of friction force depending on the micro-scratch depth for each sample is presented in Fig. 7, 8, and 9.

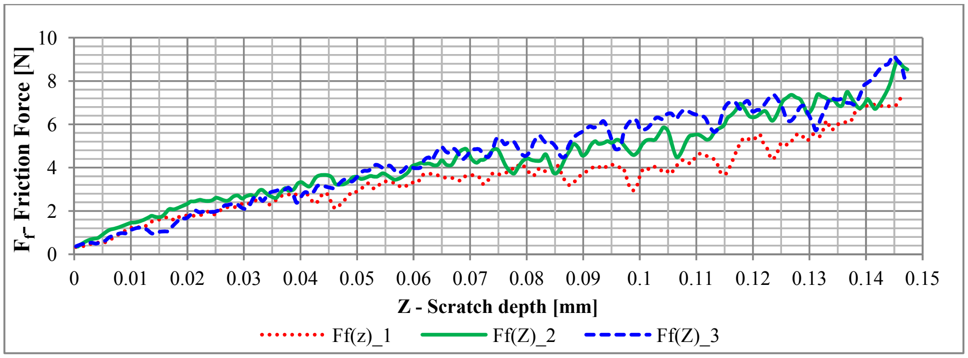


Fig. 7 Variation of friction force depending on scratch depth for FR2 sample

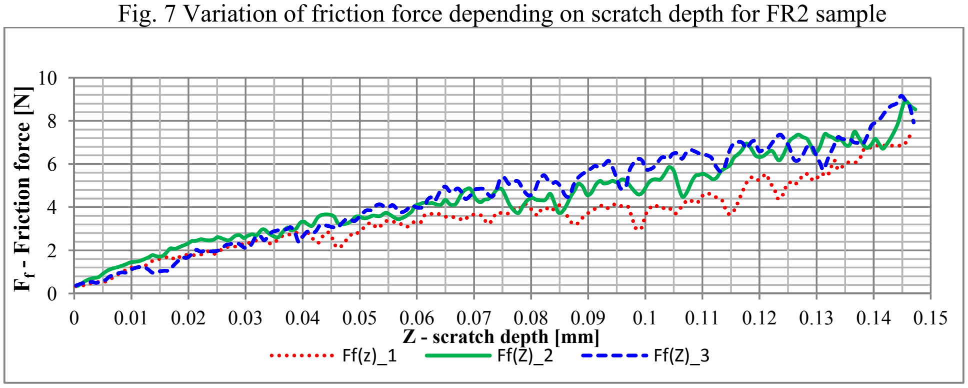


Fig. 8 Variation of friction force depending on scratch depth for FR4 sample

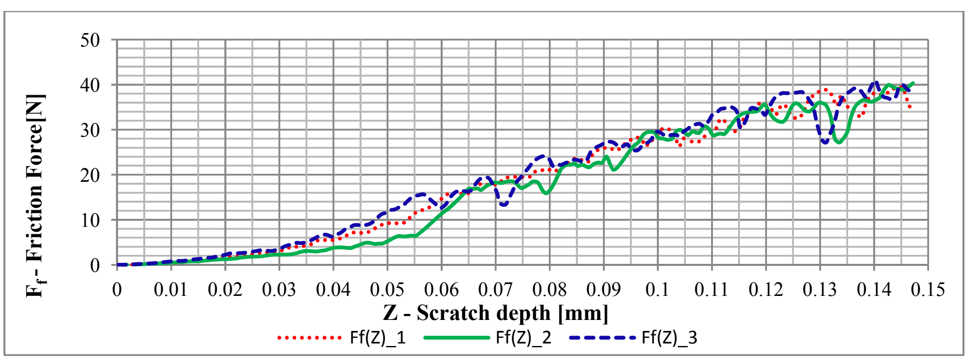


Fig. 9 Variation of friction force depending on scratch depth for CEM sample

Similar results were obtained for other scratch test made on the surface of the sample both for variation of friction coefficient and for friction force depending on scratch depth on all three samples.

The profilomety result and the images acquired at the optical inspection are presented in figure 10, 11 and 12.

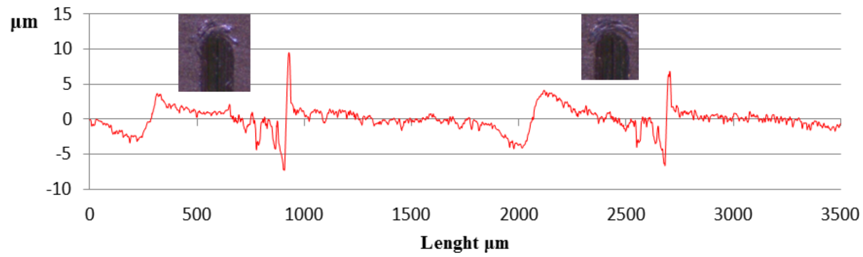


Fig. 10 FR2 profilometry for 2 scratches

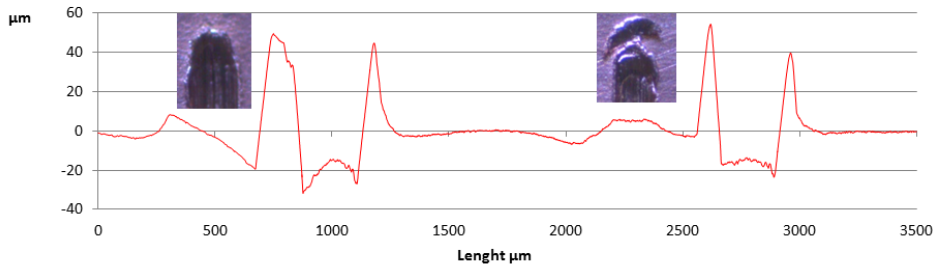


Fig. 11 FR4 Profilometry for 2 scratches

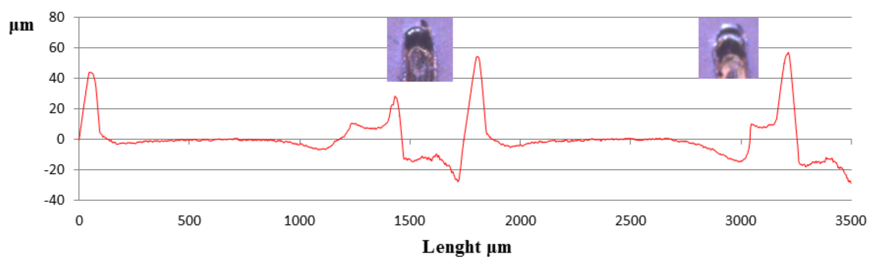


Fig. 12 CEM profilometry for 2 scratches

As result of micro-scratching test, the surface of the samples has deformed near the contact area between indenter con and rigid surface of the sample. Observing the deformation and by using the profilograms presented above the abrasion factor was determinate as being the ratio of the volume of material displaced in the process and the volume the scratch path. This method was developed by Zum Gahr for scratch profiles in ductile metals [9]

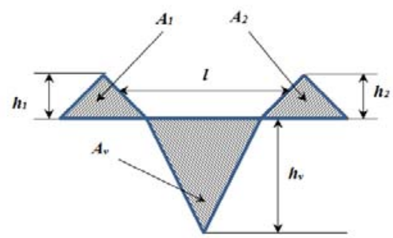


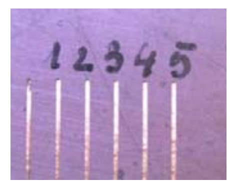
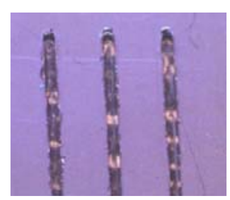
Fig. 13 Abrasion model – Zum Gahr metod

The abrasion factor formula is:

$$f_{ab} = 1 - \frac{(A_1 + A_2)}{A_v} \quad (1)$$

Table 1

Geometrical form of scratch wear and abrasivity factor

Mat.	***Scratch***	***Zone***	***A_1* [µm²]**	***A_2* [µm²]**	***A_v* [µm²]**	***f_{ab}***	***Image***
	1	End	*548.576*	*292.311*	*-397.25*	*-1.117*	
		Middle	*91.017*	*168.656*	*-286,077*	*0.922*	
		Start	*6.0025*	*63.896*	*-593.88*	*0.88*	
	2	End	*643.431*	*220.375*	*-368.187*	*-1.343*	
FR2		Middle	*158.086*	*218.579*	*-237.86*	*-0.583*	
		Start	*5.705*	*184.218*	*-166.788*	*-0.138*	
	3	End	*6.571*	*337.916*	*-181.698*	*-0.895*	
		Middle	*64.12*	*265.343*	*-374.732*	*-1.123*	
		Start	*5.022*	*148.583*	*-170.113*	*0.097*	
	1	End	*302.936*	*2426.603*	*-5317.37*	*0.486*	
		Middle	*1336.431*	*1337.184*	*-1944.08*	*1*	
		Start	*153.190*	*298.418*	*-372.951*	*-0.21*	
	2	End	*2813.401*	*1995.188*	*-4072.62*	*-0.08*	
FR4		Middle	*1711.36*	*1146.72*	*-1761.07*	*-0.622*	
		Start	*63.958*	*411.512*	*-419.086*	*-0.134*	
	3	End	*1244.968*	*1771.665*	*-2968.31*	*-0.016*	
		Middle	*936.875*	*894.687*	*-1419.64*	*-0.290*	
		Start	*111.063*	*297.438*	*-372.308*	*-0.097*	
	1	End	*2738.094*	*0*	*-482.614*	*-4.673*	
		Middle	*1452.339*	*0*	*-126.774*	*-1.456*	
		Start	*95.869*	*849.55*	*-183.654*	*-4.147*	
	2	End	*2845.85*	*3275.619*	*-4104.02*	*-0.491*	
CEM		Middle	*1020.491*	*1171.621*	*-2184.94*	*-0.003*	
		Start	*628.569*	*866.223*	*-697.624*	*-1.142*	
	3	End	*32.160*	*4464.915*	*-5600.41*	*0.19*	
		Middle	*0*	*3178.906*	*-2581.37*	*-0.231*	
		Start	*6.225*	*148.731*	*-88.803*	*-0.755*	

In Figs. 14, 15 and 16 are presented the different zones of the scratch channel, at the beginning, middle and the end of the scratch.

Fig. 14 Channel shape at the beginning of scratch for FR2, FR4 and CEM

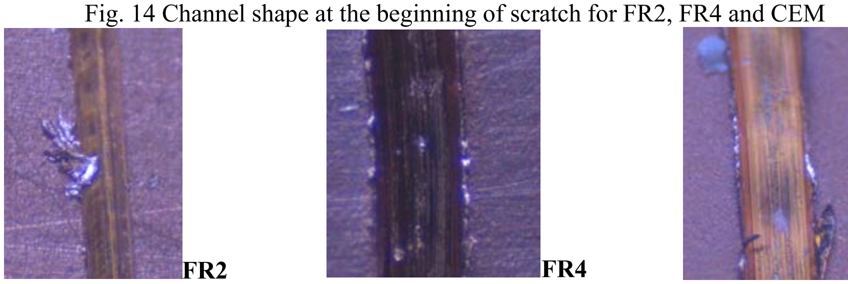


Fig. 15 Channel shape at the middle of scratch for FR2, FR4 and CEM

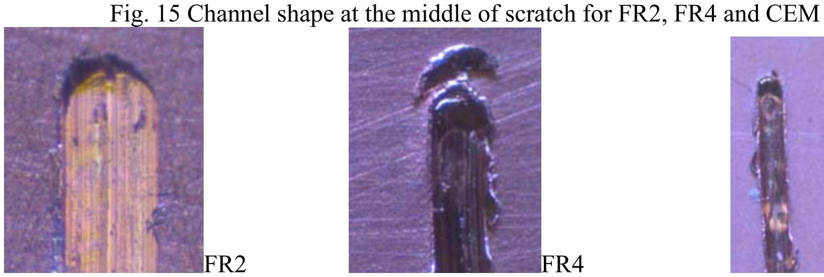


Fig. 16 Channel shape at the end of scratch for FR2, FR4 and CEM

5. Conclusions

From micro scratch point of view the conclusions are:

a) CEM sample: the indenter passes through cooper layer and penetrates the rigid support we can see these both from the optic inspection and from the diagrams presented above.

b) FR2 sample: we can't say if the indenter reaches the rigid support because in optical inspection the substrate it cannot be seen and in the diagram variation there are no changes. It is possible that de cooper layer is thicker than 0.15 mm or the FR2 support has analogue properties with cooper which is hard to believe.

c) FR4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder with a different comportment for scratching; this it can be seen from the graph representation and from the optical inspection. When the indenter gets to the fiberglass woven perpendicularly on the scratch direction, both normal force and friction force have visible variations. Same as CEM sample the FR4 substrate is affected by the scratch.

d) The friction coefficient variation with the scratch depth and length denotes the alternation of the deformation components with the adhesion components of friction force.
e) The phenomenon of cooper deformation in the presence of sliding movement contains proportional sliding and partial cold hardening.
f) The deformed material and placed in lateral and in the front of the scratch path denotes a tenacious attitude with the density attenuation as a result of sliding.
g) The removed material is “disperse” in the micro deformation process.

From scratch profile interpretation we can say:

a) The sample material deforms around the cone indenter. At optical inspection it can be seen on both sides of the scratch trace material border that leads at the idea that the tested materials have ductile properties.
b) The abrasion factor calculated in the chapter 4 has subunit values, $f_{ab}<1$, which is characteristic to tenacious materials.
c) The value of the abrasion factor increases with the hardness of the rigid support material; the highest values are observed when the indenter reaches the substrate.
d) From the profilograms it can be see that the profiles on both sides of the scratch trace are asymmetrical, most visible in CEM case. This can be either a result of material traces on the indenter con or a possible incorrect mounting of the sample on the equipment.

R E F E R E N C E S

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