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A SIMPLE BULGE TEST FOR MEASUREMENT OF DUCTILITY AND TENSILE STRENGTH OF METAL FOILS

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ABSTRACT

A simple bulge test equipment has been designed and fabricated for the measurement of ductility and tensile strength of metal foils. These values determined for thin aluminium and electroformed copper foils were found to be comparable with those reported using the sophisticated bulge testers and can be used for routine shop-floor inspection of thin foils.

Key words: Bulge test, ductility, tensile strength

INTRODUCTION

Ductility and tensile strength of electrodeposits are very useful properties in many applications. Foils made either by electroforming or rolling operations are widely used in electrical and electronic industries. Inlay technique, roll bonding, electrocladding, vapour deposition, metal spraying and a host of other techniques are used in the production of composite foils. Electroformed copper foils in thicknesses of 70 μm, 35 μm, 10 μm and 5 μm are used by the printed circuit board manufacturers. Selectively plated metal foils are utilised in the field of solar energy for insitu fabrication of flat plate collectors. The use of high purity aluminium foils by the electrolytic capacitor industry is well known. Some of the potential applications of electroformed nickel foils are as battery mesh, filters, screens, bellows, solar reflectors and collectors. Packing industries use lead, tin and aluminium foils in large quantities. In all these applications, the determination of ductility and tensile strength of thin foil is very important.

TEST METHODS

There are many tests such as the micrometer test, mandrel bend test, spiral bend test, modified Erichen cup test etc reported in the literature [1]. These tests are purely qualitative and many of them lack the requirements of a standard test, namely, sensitivity and reproducibility. Tensile pull tests [2] use either the universal testing machine or bench model machines such as Hounsefield tensometer or Instron tensile tester. They are used for determining ductility and tensile strength of massive metals, rods and thick foils. The standard grips available for holding thick sheet specimens in a uniaxial tensile test machine are not suitable for thin foils. Preparation of thin specimens [3], mounting them with proper alignment, measurement of reduction in area or length after fracture are difficult and time consuming [4]. The hydraulic bulge test method [5-7] gives the desired quantitative data on ductility and tensile strength in a much easier way.

In this method, the foil sample in the form of a circle or a square is clamped suitably over an orifice in a circular platen. Hydraulic fluid is pumped through the orifice and the pressure developed baloons the flat specimen to form a segment of a spherical cap known as the bulge. The hydraulic pressure applied, the deformation of the foil at the apex of the cap and bulge height at the apex are recorded by suitable measuring devices. The pressure is increased continuously till the bulge fractures. The hydraulic pressure and bulge height at fracture are noted. From these two readings elongation and tensile strength of the foil are calculated using derived equations [5].

Percentage elongation $\% E = \dfrac{100\, h^2}{2 r^2}$

and tensile strength, $T = \dfrac{P(r^2 + h^2)\left(1 + \frac{4h}{r}\right)}{4th}$

where h = bulge height in cms; r = radius in cms, P = pressure in kg/cm^2 and t = thickness of the foil in cms.

Improvements have been made in the original design of the bulge tester by several authors [8-14]. Modifications have been made in the mode of clamping the specimen, applying the hydraulic pressure at standard rates and continuous recording of the bulge height and pressure. All these attempts have made the machine a highly sophisticated research tool to investigate and understand the mechanism of fracture of thin foils.

If the test method is to serve as a workshop inspection tool, it should meet the following demands:

(i) It should give a quantitive measure of elongation and tensile strength as measured by the accepted standards of interpretation.

(ii) The specimen preparation and mounting on the machine should be quick and easy.

(iii) The number of measurements to be made to get the desired data should not be large.

(iv) The measurements should be reproducible, reliable and sensitive.

(v) The equipments should be operable with minimum technical skill by the inspection department.

(vi) Should be robust and easy to handle and

(vii) The overall cost should be within the reach of a small workshop inspection section.

DESIGN OF THE TESTING EQUIPMENT

Keeping the above criteria of a simple test equipment which could be used by any skilled worker, an attempt has been made to design an apparatus with materials which are either available or can be fabricated locally. From the data available in the literature it was observed that 150 μm metal foils would bulge to rupture at pressures of 6-7 kg/cm^2. The line drawing and the photograph of the machine designed is shown in figures 1 and 2 respectively.

A hand operated hydraulic pump (A) which could transmit the hydraulic pressure to the specimen up to 10 kgf/cm^2 was procured. A cylinder (B) which could act as a base plate for holding the specimen as well as store hydraulic fluid and transmit pressure, was to be machined. The diameter of the specimen to be bulged was arbitrarily fixed at 50 mm so that the diameter: thickness ratio of the specimen was more than 300: 1 [11]. Hence the outer diamter of the steel cylinder was taken as 100mm with a wall thickness of 10mm to withstand pressures up to 10 kgf/cm^2. For transmitting the hydraulic oil under the specimen a hole of 20mm thick and 100 mm outer dia with a concentric hole of dia 50 mm. The foil specimen (F) was placed on the

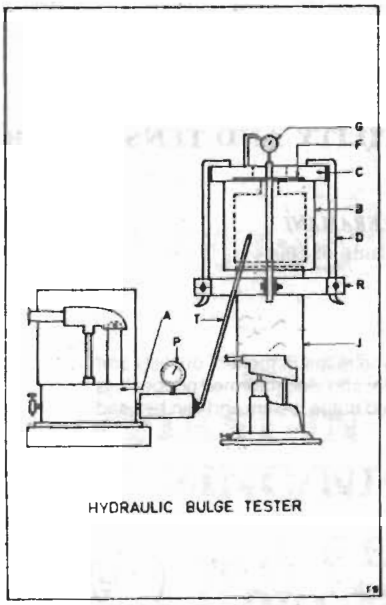

Fig.1 Line drawing of the hydraulic bulge tester

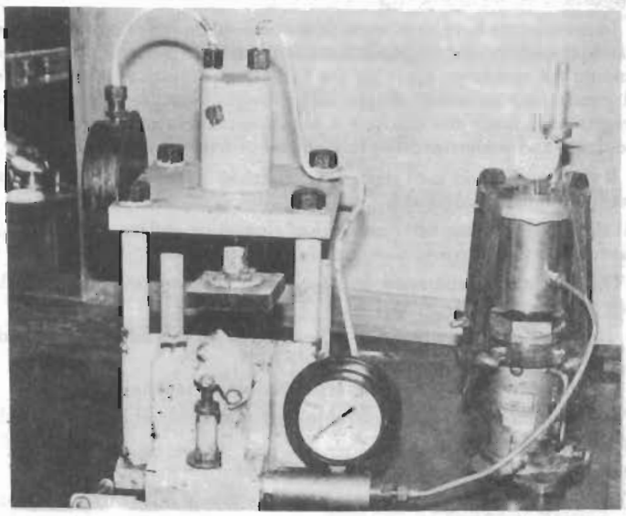

Fig.2 Experimental set up - full view

top surface of the cylinder and the ring (C) was placed on top of the specimen so that the two circular holes are concentric. The clamping of the specimen should be slip proof as well as easy to mount and to remove quickly. A load of 6 tons was required for this purpose. To transmit this load a hydraulic jack (J) of 8 tons capacity was used. To distribute the clamping force uniformly on the periphery of the specimen, four clamps (D) welded to a ring (R) of diameter 160 mm and thickness 20 mm were designed. The ring (R) slips around the circumference of the hydraulic jack (J). The transmission of hydraulic oil from the press to the cylinder (B) was through a seamless copper tube (T) of 6 mm diameter. The hydraulic pressure was measured by a sensitive dial guage (G). The disadvantage of the contact pressure that may be exerted by the pointer of the guage on the specimen which may induce premature rupture was noticed. In order to minimise this error due to contact pressure, the dial was set to zero after every increment of height and totalled to get the actual height. A closeup view of the cylinder B, with ring R and clamps is shown in figure 3. The specimen holder ring C and specimen foil are also shown. Figure 4 shows the specimen under test with dial guage in position.

Figures 5 and 6 show aluminium and copper foil specimens bulged to fracture.

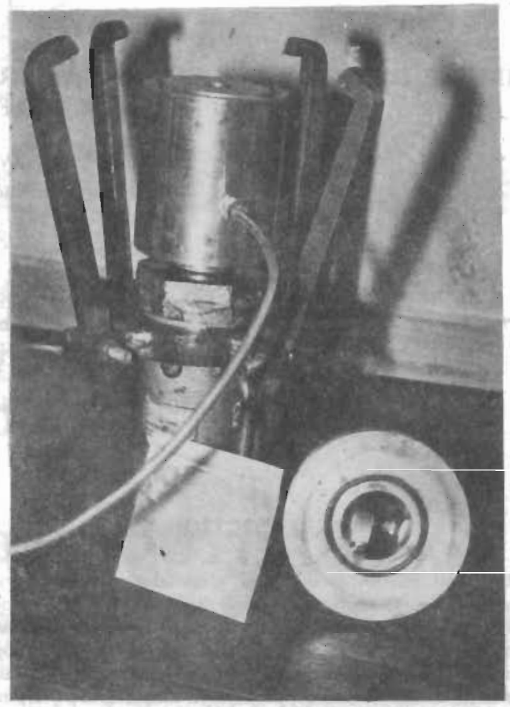

Fig. 3 A close view of the cylinder with ring and clamp arrangement

EXPERIMENTAL

The foil specimen of diameter 100 mm (need not be exact) was cut from the electroformed or rolled foil so that the specimen area is free from pinholes, dents and other physical deformations due to handling and placed centrally over the top surface of cylinder B with the clamping ring placed centrally on top of it with care not to deform or disturb the specimen from its position. The four clamps D are brought into position and tightened by the hydraulic jack. The dial guage is then lowered into position to make just contact at the centre of the specimen. Then pressure is gradually increased by means of pumping oil from the hydraulic pump. Readings of pressure and bulge height are noted for every increase of 0.25 kgf/cm^2 pressure. These intermediate readings need not be recorded if ductility and tensile strength at fracture alone are required. The experiment is carried out till the specimen ruptures. The final height and hydraulic pressure are noted. The specimen removal and mounting take less than 5 minutes every time. The total duration of an experiment is less than 15 minutes.

RESULTS AND DISCUSSION

Two lots of aluminium foils, one superpurity used in electrolytic capacitors (100 μm), and the other used in photo offset lithoplates of office duplicating machines (150 μm), and two lots of copper foils, one imported electroformed sample (110 μm) and the other electroformed in our laboratory from an acid bath by batch process (100 μm) were tested. The results are shown in Table I. Tensile strength and percentage elongation at fracture were calculated from equations 1 and 2 respectively. The reproducibility of the test data is evident when one compares the tensile strength and ductility values of the two copper foils nearly of same thickness (lot 3 and lot 4).

CONCLUSIONS

A simple hydraulic bulge tester for routine shop-floor inspection and for comparative evaluation of elongation and tensile strength of thin foils is reported in this study. The cost of the machine works out to Rs 5000. However, if the hand operated hydraulic pump and the hydraulic jack can be

Fig. 4 Specimen under test with dial gauge in position

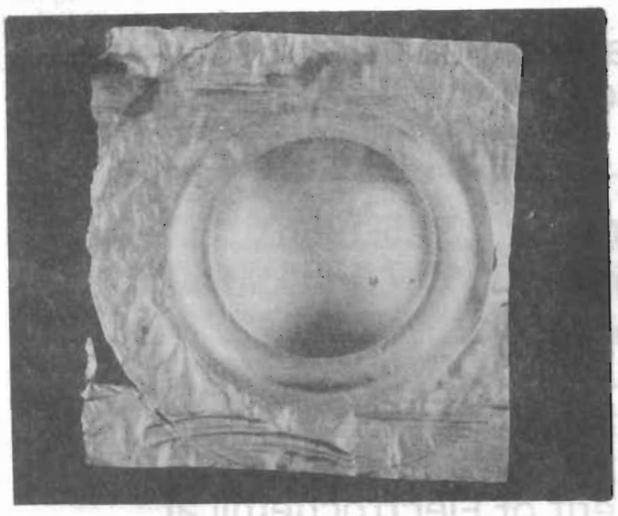

Fig. 5 100 μm thick aluminium foil after the specimen is subjected to bulge test

dismembered temporarily from other assemblies, as was done in our work, the cost of the machine is insignificant.

Sample preparation for testing and mounting takes very little time. The required data can be obtained in less than 5 minutes, as only two readings, viz. the bulge pressure and bulge height at fracture are to be noted. The test equipment can be handled by a skilled-workshop assistant with minimum training.

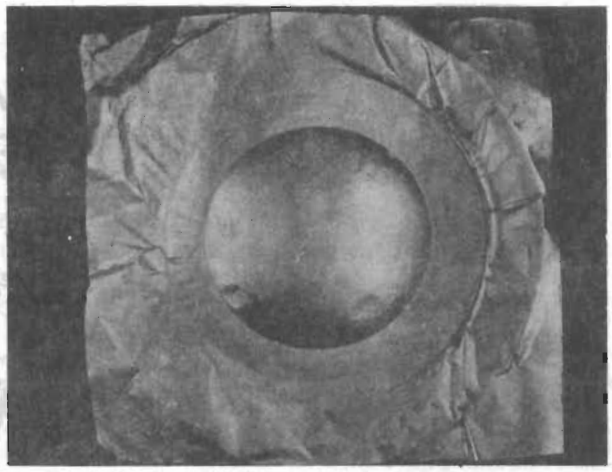

Fig. 6 100 μm thick copper foil after the specimen is subjected to bulge test

Table I Percentage elongation and tensile strength at fracture for aluminium and copper foils

Lot. No.	Expt. No.	Foil Material	Thickness μm	Pressure at rupture kg/cm^2	Height of bulge at rupture (mm)	Percentage elongation	Tensile strength kg/cm^2
1	1	Aluminium (capacitor foil	100	2.0	9.80	7.68	944.50
	2	-do-	100	2.0	9.60	7.37	947.25
	3	-do-	100	2.0	10.06	8.09	941.88
	4	-do-	100	2.0	9.60	7.37	947.25
	5	-do-	100	2.0	9.32	6.94	951.39
	6	-do-	100	2.0	9.40	7.06	950.12
2	1	Aluminium (Offset foil)	150	3.0	11.10	9.85	1403.27
	2	-do-	150	3.0	9.90	7.84	1414.04
	3	-do	150	3.0	10.59	8.97	1406.48
3	1	Copper foil (Proprietory)	150	6.0	11.70	10.95	2805.31
	2	-do-	110	6.0	11.50	10.58	2550.10
	3	-do	110	6.0	11.20	10.035	2551.01
4	1	Copper foil (CECRI)	100	3.5	9.40	7.06	1543.97
	2	-do	100	3.3	7.60	4.60	1642.39
	3	-do	100	3.0	9.10	6.62	1432.73

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