The Construction of Bodies of Moderate Conductivity for Electromagnetic Scale Modelling Experiments

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Introduction

Scale modelling techniques have been widely used to prepare type curve suites for electromagnetic prospecting systems for geometries where the mathematics is too intractable for analytical or numerical solution. However, the literature provides scant information on the physical construction of models, and it has been our experience that model building is no easy task. Some knowledge of the problems involved in building models was acquired during the course of a recent modelling project (Drinkrow and Duffin, 1976). We are publishing this note to help future modellers circumvent some of the practical problems which we encountered.

Models of intermediate conductivity

There is a gap in the conductivity spectrum of commonly available materials. The gap occurs between the electronic conductors, such as the metals (e.g. aluminium alloy sheet, $\sigma \approx 1.7 \times 10^7$ siemens/m) and slab graphite ($\sigma \approx 2.0 \times 10^5$ S/m), and the ionic conductors (e.g. 20% brine solution, $\sigma \approx 16$ S/m at 15°C). Unfortunately, if the requirements of scale modelling theory are to be satisfied, the conductivity of the model must sometimes fall within this gap.

Modellers have generally resorted to constructing synthetic bodies by loading a suitable binder with conducting particles. The mixing ratio is chosen so that conduction is maintained by point-to-point particulate contact. To provide a wide range of conductivities the binder and the conducting material should be miscible over a wide range of proportions and yet still result in a model that is:

(a) isotropic and free of electrical and physical inhomogeneity;

(b) self supporting;

(c) denser than the fluid in which it is immersed for the modelling experiments, but not so dense that, at the scaling factors used, it cannot be conveniently handled;

(d) composed of materials that are cheap and readily available.

Conducting epoxies and plastics have been commercially available for many years. However, as silver flake is generally the conductive component, these products have a high unit cost. Bronze particles in a wax host have been used by Pritchett (1955), but the compound suffered from mechanical flow and loss of uniformity. Iron filings and brass powders in binders of cement, plaster of Paris and araldite were tried by Apparao *et al.* (1969). They report problems in achieving low resistivity values with such mixtures and mechanical disintegration when immersed in the electrolyte. Copper filings in gelatinous media have been reported in a few unpublished theses, and Lukjanov (1950) used copper sulphate in an agar-agar gelatin host. However, such bodies are again not mechanically competent.

In any case, metallic powders generally give conductivity values similar to, or of an order of magnitude less than, the conductivity of graphite slabs, whilst inorganic salts give values of the same order as brine. In order to prepare a material with a conductivity in the range $10^2 - 10^3$ S/m (roughly in the centre of the spectral window) previous experimenters have used mixtures based on graphite powders. Godsey (1935) used a mixture of carbon and wax, whilst Apparao *et al.* (1969) and Frischknecht (1971) used models made from graphite and cement. However the mechanical properties of these models were very poor, particularly at high graphite content and Frischknecht went on to use a mixture of graphite powder and polyester 'lay-up' resin. Using reasonable mixing ratios he obtained conductivities of 50-350 S/m but he noted that these figures are very dependent on the physical treatment of the mixtures and on the type of graphite filler used. He also reported a high conductivity rim around the moulded bodies, created in the casting process.

As no further information on the use of synthetic resins for modelling purposes is available in the literature, a short experimental program was initiated.

Graphite and resin bodies

Trial castings

There are three distinct types of synthetic resins available in 'two-pot' form – the polyesters, the polyurethanes and the epoxies. Epoxies are very expensive and their use was not considered. The polyurethanes, which are more expensive than the polyesters, had not previously been used for model construction and were therefore included in the experimental program. Although Frischknecht (1971) used a polyester 'lay-up' resin, an alternative material, casting resin, is available with a considerably reduced exotherm. Large solid castings, which do not crack during the cooling phase, can be produced with this resin. Further, the material is available* with a specified maximum exotherm temperature and controlled 'promotion' giving an extended pot-life.

Trial castings consisting variously of agricultural zinc dust and polyester resin, zinc dust and polyurethane, graphite powder and polyurethane, and graphite and polyester were made. Several grades of graphite powder were used. However, the zinc dust bodies and the graphite and polyurethane bodies were found to be non-conductive (the former probably because the zinc dust grain-size was too small to establish point-to-point contact, and the latter because the polyurethane completely wetted, and so encapsulated, each graphite grain). The graphite and polyester resin produced bodies which were conductive, although their homogeneity and rigidity under stress depended strongly on the type and amount of graphite added to the filler. Very fine-grained "microfine" graphite powders and fine-grained flake graphite produced the least stable compounds.

*Synthetic Resins Pty Ltd, type 336P; Daystar Chemicals, type P720.

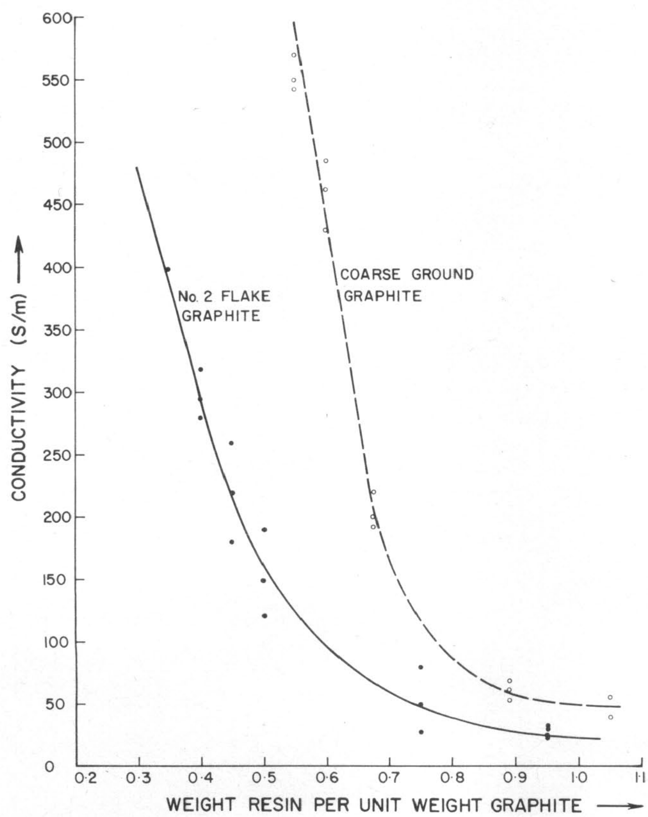

FIGURE 1
Conductivity as a function of resin/graphite ratio for two graphite types.

Additional experimentation was done to provide data on body conductivity as a function of resin-to-graphite ratio for several graphite types and grades. Curves for two are shown in Fig. 1, one for "number 2 flake graphite", a high quality, low impurity graphite, and the other for "coarse ground graphite†", a cheaper synthetic product. Note that, for a given conductivity, the resin-to-graphite ratio for the coarse ground graphite body is about twice that for the flake graphite. This means that the cheaper graphite produces a much harder and stronger product than the purer variety.

Finally, extrapolation to the left on the ratio axis on Fig. 1 to obtain higher conductivies should not be attempted. The chemical reaction process in the resin which produces the hard product is retarded or inhibited beyond a certain graphite content.

Full-sized models

The full-sized models were made by mixing the graphite powder into the resin using small spades and a wide-pronged fork. The general consistency of the mixture was that of wet sand, and puddling it to form an homogeneous mix required considerable effort. As the material had a gel-time of about 30 minutes, the largest model that two people could produce, and ensure uniform mixing, weighed about 100 kg.

The models were cured under a pressure of about 7 kPa. The curing process differed from Frischknecht's in that it produced two thin surface layers. The outside layer was a resin-rich non-conductive zone about 1 mm thick, while below it was a thinner graphitic zone. Both these layers were easily ground off, and the remaining body was found to be homogeneous and isotropic. The surface impedance of the body was low and galvanic contact between it and a host solution was readily confirmed.

A photomicrograph of a polished section of a sample with resin-to-graphite ratio of 0.60, conductivity 480 S/m and

†Union Carbide graphite powder AG5R.

FIGURE 2
Photomicrograph of polished section of graphite and resin body. The resin is a polyester and the graphite is a coarse grained synthetic product. Average grain diameter is about 0.3 mm.

density 1.45 g/cm^3* is shown in Fig. 2. The point-to-point contact of the graphite can easily be seen, particularly when a three dimensional extrapolation is made. The average diameter of the graphite grains in this photograph is about 0.3 mm.

References

APPARAO, A., A. ROY, and K. MALLICK, 1969. Resistivity model experiments, *Geoexploration 7,* 45-54.

DRINKROW, R.L. and R.H. DUFFIN, 1976. Scale model type curves for down-hole electromagnetic logging in a conductive environment, *CSIRO Minerals Research Laboratories, Investigation Report 120.*

FRISCHKNECHT, F.C., 1971. Electromagnetic scale modelling, *in* Electromagnetic Probing in Geophysics, 265-320, J.R. Wait (ed.), Golem Press, New York.

GODSEY, F.W., 1935. Two methods of mapping flux lines. *Elect. Engng. NY 54,* 1036.

LUKJANOV, A.V., 1950. Electrolytic modelling of space problems, *Dokl. Akad. Nauk. SSSR, 75(5),* 613.

PRITCHETT, W.C., 1955. A low frequency electrical earth model, *Geophysics* 20, 860-870.

*Maximum density of near-saturated brine solution at 15°C is about 1.28 g/cm^3.