# Development of electrical insulating surface on copper-nickel alloy wire used in naval instruments

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THE copper-nickel alloy wire used for close-wound resistors in Naval instruments is an oxidized wire having 0·001 cm thick oxide which offers electrical insulation to a potential difference of about 15 volts. At present, the oxidized wire used by the Navy is of imported origin. A problem has, therefore, arisen to develop a process for producing the oxidized wire locally. Work was, therefore, taken in Naval Chemical and Metallurgical Laboratory, Bombay, to find the experimental conditions to produce the oxidized layer with requisite electrical insulation characteristics.

### Theory

Materials used for electrical insulation are generally those having such high electrical resistivity that the flow of current through them is negligible. Thus the insulation serves the purpose of supporting a potential difference between two or more conductors while limiting the leakage current to a negligible value.

The electrical insulation offered by the oxide layer of copper nickel alloy (56 Cu/43 Ni with 1% Mn) is based on the semi-conducting property exhibited by the cuprous oxide ($Cu_2O$), nickel oxide (NiO) and manganese oxides formed, on the surface of the alloy, on oxidation at high temperatures. All the oxides formed on oxidizing this alloy are the known semi-conductors.

The copper-base alloys oxidize at rates different from that of pure copper depending on the effect of alloying element. Pure copper oxidizes at around 150°C according to inverse logarithmic and direct logarithmic relationship with time. Above about 200°C to 1000°C, the oxidation of copper is essentially parabolic with time (Fig. 1). Tylecote observed that the oxidation of copper depends on temperature as shown in Fig. 2. The effect of oxygen gas pressure is given in Fig. 3. The oxidation rates of nickel were reported to be similar to that of copper. Copper-nickel alloys of the type being now

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**SYNOPSIS**

*The copper-nickel alloy wire used in Naval instruments is a 60/40 alloy wire with oxide layer on its surface for providing the necessary electrical insulation to 15 volts.*

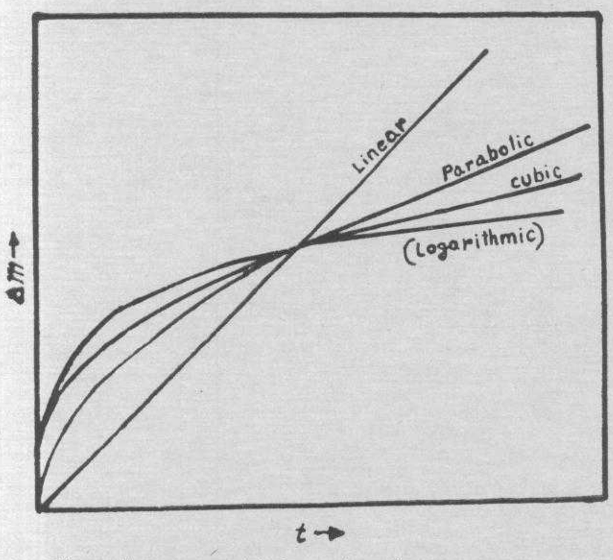
*The work carried out at Naval Chemical and Metallurgical Laboratory consists of studying the oxide surfaces produced on the alloy wire under various conditions of temperature, flow rate of oxygen and time. The temperatures studied were from 600°C to 1000°C at intervals of 50 degrees. The flow rate was varied from 1 litre per minute to 10 litres per minute. The time of oxidation was from 1 minute to 20 minutes.*

*The electrical insulation offered by the oxide was evaluated by applying gradually increased voltage across the cross section of the wire and noting the voltage at which the insulation becomes ineffective as indicated by a large current shown in the ammeter of the test circuit.*

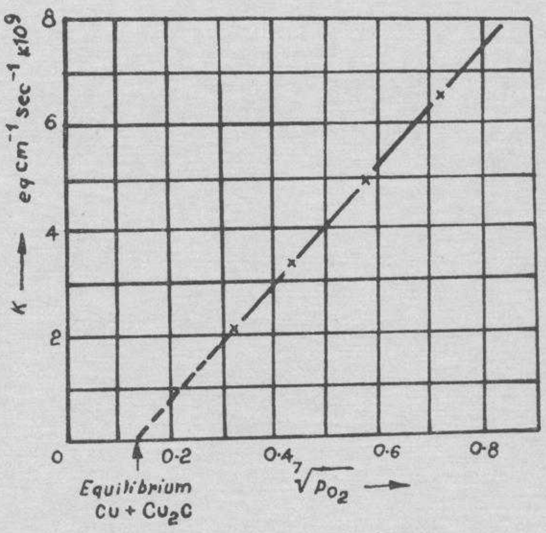
*The work carried out here indicated that the oxide layer formed on the wire at a temperature of 750°C by passing oxygen for one minute at the rate of 5 litres/minute would be suitable for developing a process to oxidise the wire for the purpose envisaged.*

studied were reported to have higher oxidation rates compared to pure nickel or pure copper. The addition of manganese to the copper up to 1·5% helps in producing adherent scales to the alloy. It was also reported that a small addition of manganese increases the oxidation rate of nickel.

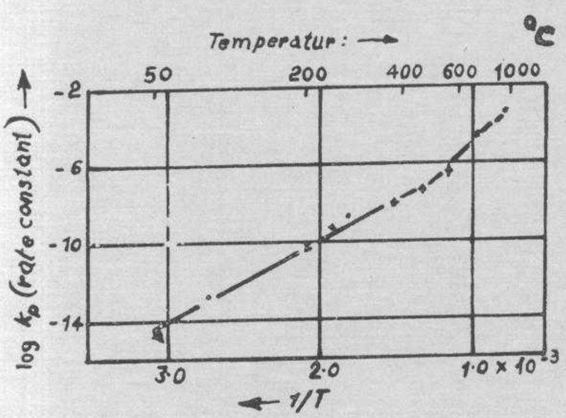
Copper forms on oxidation, two oxides viz., cuprous oxide ($Cu_2O$) and cupric oxide (CuO). It was indicated that under conditions of high temperature reaction, cupric oxide is not stable and cuprous oxide ($Cu_2O$) is the only oxide present. Pure nickel oxidizes at high temperatures with the formation of nickel oxide (NiO). The oxidation of copper-nickel alloys was studied by Frohlich. He observed the formation of subscales rich in copper containing inclusions of the solute oxides. An alloy of the type 62 Cu/38 Ni investigated by




1 *Effect of time on oxidation rates of copper (Reproduced from 'Oxidation of Metals and Alloys' by Kubaschewski O. and Hopkins B. E.)*

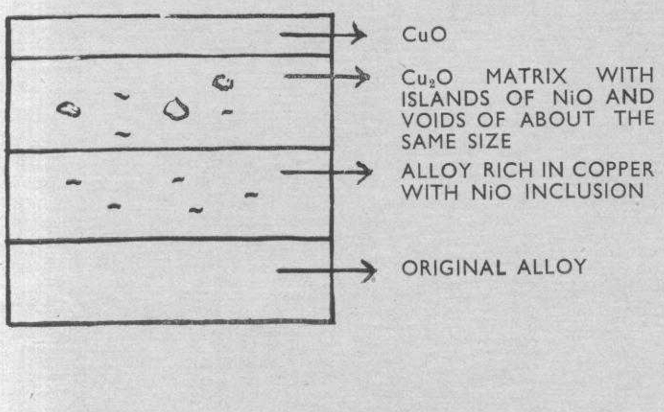



3 *Effect of gas pressure on oxidation of copper (Reproduced from 'Oxidation of Metals and Alloys' by Kubaschewski O. and Hopkins B. E.)*




2 *Effect of temperature on oxidation rate of copper (Reproduced from 'Oxidation of Metals and Alloys' by Kubaschewski O. and Hopkins B. E.)*

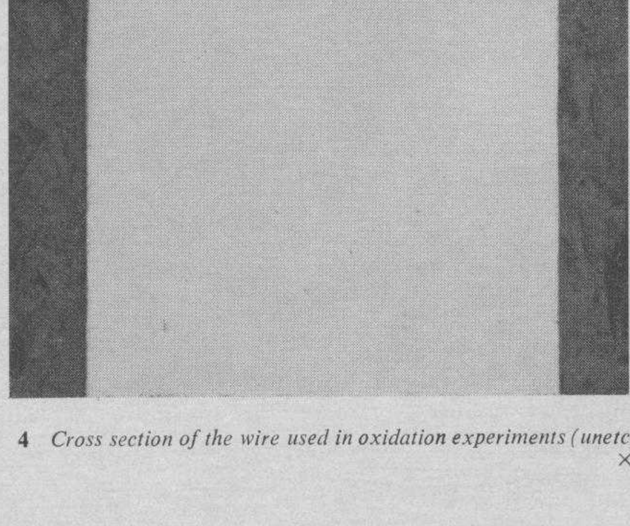
Sartell is similar to the alloy now being considered. He observed that a sequence of oxide layers depicted below formed on oxidation at 620–930°C.



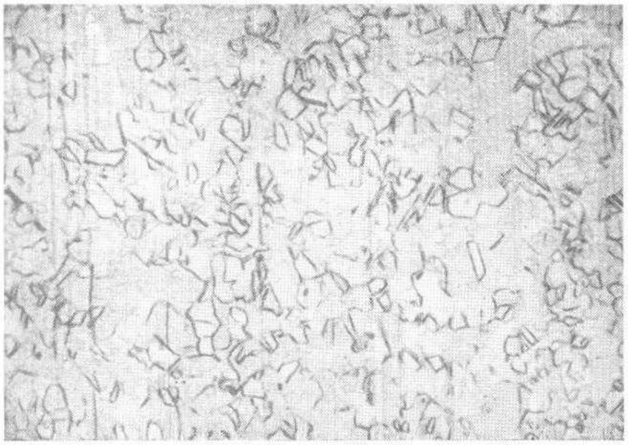

The above sequence of oxide formation could be assumed for the oxidation of the alloy under study, with presence of manganese oxides in the layer adjacent to the original alloy.

**Experimental technique**

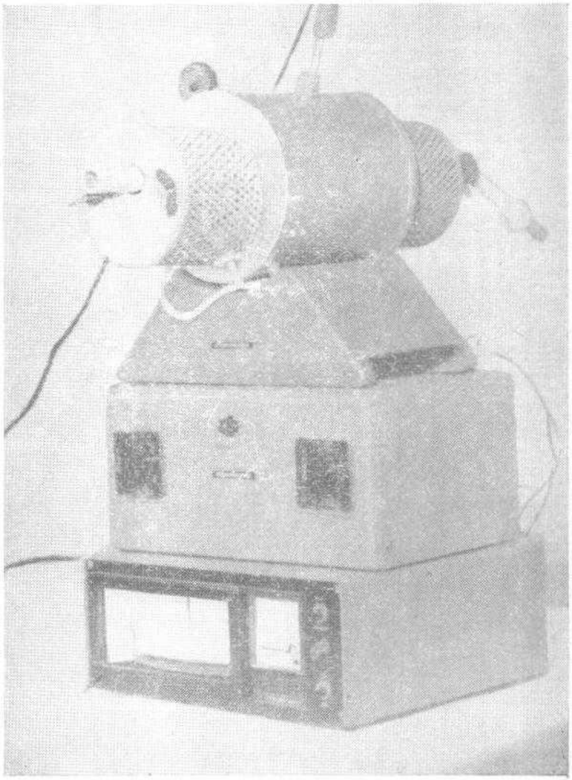
Copper-nickel alloy wire (Eureka) used in the experiment is of 21 SWG (Fig. 4) and of the chemical composition, 56 per cent copper, 43 per cent nickel, 1 per cent manganese. Tensile strength of the wire was 32 000 pounds per sq. inch. The microstructure of the material is shown in Fig. 5.



4 *Cross section of the wire used in oxidation experiments (unetched) ×125*

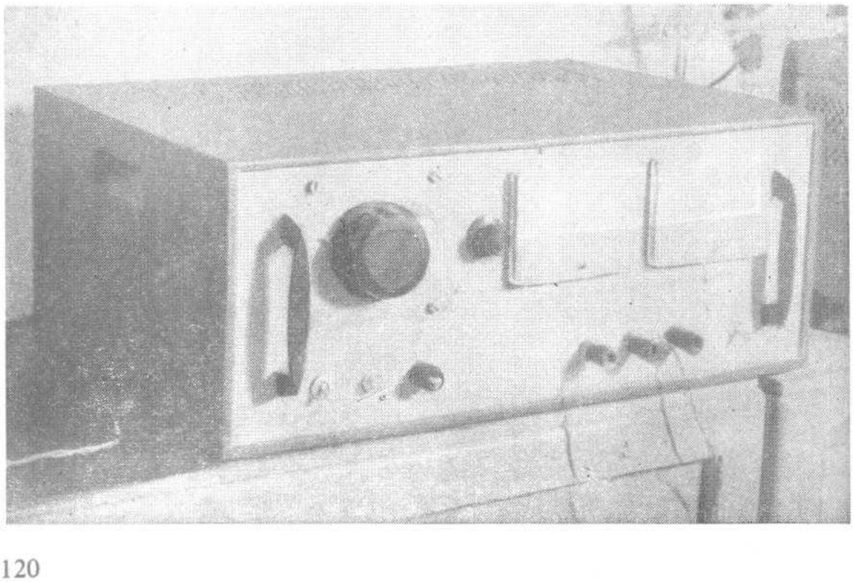


5 *Microstructure of the wire* ×500

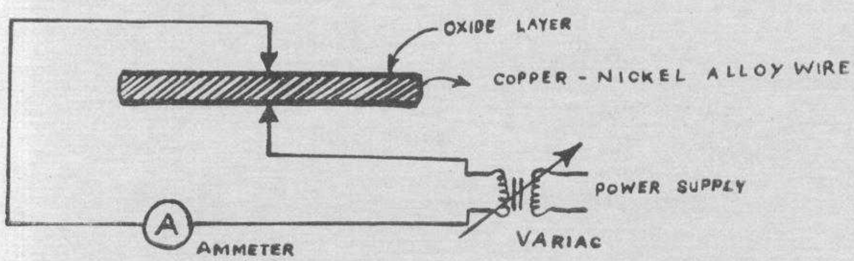


6 *Tubular furnace used for heating the wire samples*

Four-inch long pieces of the wire were taken, degreased with organic solvent and were kept in the central zone of the tube of the furnace (Fig. 6) where the prevailing temperature is the same as shown by the temperature indicator. Experiments were initially carried out at different temperatures by passing air as the oxidizing medium. These experiments revealed that the oxide layers produced on the alloy surface were either non-adherent, non-uniform or required longer periods of oxidation to produce sufficiently thick layer. Since the present work is intended to develop a process to oxidize the wire by a continuous process, longer times of heating are not preferred as the production rate per unit time will be less. Hence, experiments were then carried out by using only oxygen gas as the oxidizing medium. The conditions studied were the effect of temperature, time and gas flow rate. Temperatures studied were from 600°C to 1000°C, the time of oxidation going up to 20 minutes and the flow rate followed was from 1 to 10 litres/minute. The experiments were carried out only from 600°C as it was indicated by Tolecot that the oxide formed in copper below 600°C was not adherent. Those observations were confirmed by the authors of this paper by actually carrying out the experiments below 600°C. The oxide layers formed under different conditions mentioned above were examined



7 *Power supply unit used for assessing the electrical insulation of oxide layer*




8 *Insulation testing circuit*

by studying the longitudinal section of the wire using normal metallographic methods of polishing and etching the copper-base alloys. The electrical insulation offered by the oxide layer was evaluated by using the equipment shown in Fig. 7 and as per the test circuit shown in Fig. 8.

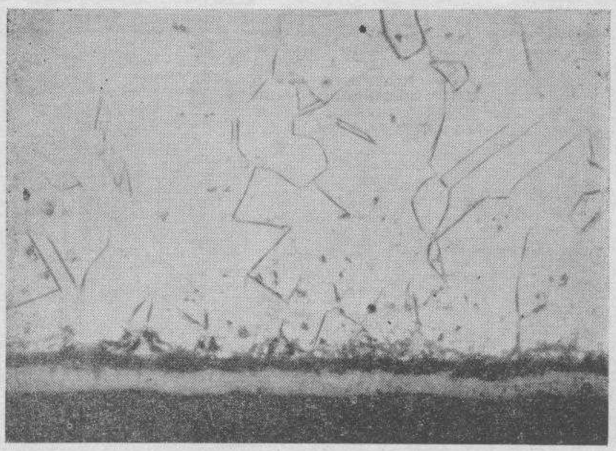
**Results**

The results obtained from the various experiments carried out using oxygen gas as oxidizing medium are shown in the Table I. The authors carried out a large number of experiments to know the effect of time and gas flow rate at each temperature. It was observed that a minimum gas flow rate of 5 litres per minute was required for oxidizing this alloy. Further increase in gas flow rate has no effect on oxidation rates. The effect of time at any temeprature was to

**TABLE I Insulation resistance of the oxide layer**

| Sl. No. | Temperature (°C) | Time of heating with oxygen gas (in minutes) | Flow-rate of oxygen (litre/min.) | Insulation resistance of the oxide layer (expressed in volts withstood before breaking) |
|---|---|---|---|---|
| 1. | 600 | 1 | 10 | 2 |
| 2. | ,, | 2 | ,, | 4 |
| 3. | ,, | 4 | ,, | 4 |
| 4. | ,, | 6 | ,, | 5 |
| 5. | ,, | 8 | ,, | 6 |
| 6. | ,, | 10 | ,, | 6 |
| 7. | ,, | 15 | ,, | 7 |
| 8. | ,, | 20 | ,, | 8 |
| 9. | 650 | 2 | 10 | 2 |
| 10. | ,, | 4 | ,, | 4 |
| 11. | ,, | 6 | ,, | 4 |
| 12 | ,, | 8 | ,, | 6 |
| 13. | ,, | 10 | ,, | 8 |
| 14. | ,, | 15 | ,, | 30 |
| 15. | ,, | 22 | ,, | 40 |
| 16. | 700 | 5 | 10 | 50 |
| | | 10 | 10 | 200 |
| 17. | ,, | 10 | 5 | 200 |
| 18. | 750 | 1 | 5 | 40 |
| 19. | ,, | 2 | 5 | 70 |
| 20. | 800 | 1 | 5 | 75 |
| 21. | 850 | 1 | 5 | 150 |
| 22. | 900 | 1 | 5 | 200 |
| 23. | 1000 | 1 | 5 | Completely oxidized |

9 *Microstructure of the imported oxidized wire* ×*500*
*(thickness of oxide layer 0·001 cm)*



10 *Microstructure of the wire with the oxide layer developed by the authors* ×*500*
*(thickness of oxide layer 0·001 cm)*

increase the thickness of oxide layer as indicated by the previous workers. It was observed that the higher temperatures produce thicker oxide layers in shorter periods of heating compared to those produced at lower temperatures. From the various results obtained in the experiments, it was observed that the oxide layer and the microstructure of the alloy (Fig. 9) produced when the alloy was heated to the temperature of 750°C for one minute under oxygen flow rate of 5 litres per minute would give the performance (in respect of electrical insulation) which can well be compared with that of the oxide wire (Fig. 10) at present being used in the Navy.

Based on the above observations the authors have decided to design suitable equipment for oxidizing the wire by a continuous process. The authors also decided to follow the above process although the insulation offered is better than actually required. This is due to the fact that, in a continuous process, it would be very difficult to ensure uniform layer of oxide and hence any area which has slightly less thick oxide layer would also give the desired insulation.

## Acknowledgement

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## References

1. Kubaschewski, O. and Hopkins, B. E. : 'Oxidation of Metals and Alloys', 1962.
2. Karl Hauffe : 'Oxidation of Metals'.