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RESEARCH ARTICLE

The effects of soldering flux type on corrosion properties of electrical wires

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Abstract

Electrical wires are used in many applications with increasing amounts especially in constructions and buildings. These electrical conductive wires are mainly manufactured from 99.9% (by weight) electrolytic copper with restricted minor amounts of other alloying elements. Copper wires are joined by soldering operations for high electrical conducting efficiency. Soldering flux usage is a must in soldering operations where higher corrosion resistance with satisfactory adhesion property is in concern for increasing joining quality. Soldering flux exhibits an important role related with adhesion and corrosion properties of the joints. In this study, three different types of soldering fluxes were used in soldering operation of electrical copper wire. Corrosion test is applied on soldered wires with also unsoldered raw copper wire by immersing in 20%NaOH solution by 96 hours of duration time. Comparison of corrosion resistance of samples is investigated by weight loss principle according to ASTM G1 standard document. The highest corrosion resistance was observed on samples joined with a solder flux of having majorly zinc and ammonium chloride while the least corrosion resistance was observed on samples joined with flux containing halides.

1. Introduction

Electrical wires are composed mainly of electrolytic copper with various elements in limited amounts. They have been used for electrical conductivity purposes in many construction areas [1-5]. These efficient electrical conductor materials are joined by numerous types of soldering and brazing techniques for increasing joining ability and improving electrical conducting performance. Soldering or soft soldering is especially preferred mainly for ensuring electrical conductivity while brazing or hard soldering is applied for also increasing the joint strength as needed.

Solders are mainly composed of lead and tin alloys reacting with the substrates. The most widespread type of solders for soft soldering is approximately %63Sn and remaining amounts of Pb element. This is an eutectic composition as the melting point is too low (≈183°C) for these alloy series between lead and tin letting easier melting in soldering. The products of solder-substrate reactions are composed of inter-metallic compounds such as Cu_3Sn (ε) and Cu_6Sn_5 (η) that can also provide strengthening effect on the joint but letting them responsible for cracks in soldered regions. There are also other types of inter-metallic compounds but they behave less harmful to joint performance as compared with Cu-Sn types.

In soldering, a suitable flux is used for cleaning surfaces from oxides, various dirt and tarnishes etc. The reactions between the solder and the substrate material play an important role on soldering quality.

Non-metallic layers such as oxides originating from atmospheric oxygen, sulfides or other types of contaminations on substrate materials prevents this reaction and obstacles the joining stage. Whether the contaminations are completely removed by using soldering fluxes, the joining reactions between solder and substrate can occur safely. When the flux could not remove all of the surface contamination from the joint faces, the solder will not be able to penetrate fully into the joint and the joint will get weaker. Flux reduces the solid oxide skin and transforms it into a soluble salt. When more amounts of cleaning action are required in some surfaces due to the substrate material, the flux must have more acidic character to accomplish it. Besides the wetting capability of a flux has to be adequate for effective cleaning action, the flux must be at the liquid phase at the soldering temperature for perfect wetting and covering property. Fluxes should retain their mobility during the soldering operation and can be easily removed from the substrate material after cooling when the soldering is completed.

Some fluxes may contain organic and inorganic compounds, resins and halides (as chlorine ions) etc. Natural resin is a distillation product of the sap of pine trees. Chemically, it is a mixture of several organic acids and their close relatives. Halides are composed basically of salts as they can cause corrosion damage in soldering operations so that the joint must be carefully cleaned [6,7].

Table 1. Chemical composition of UNS C 11040 electrical copper wire [1,2]

Elements (%by wt.)							
Cu	Pb	Fe	Ag	As	O	Sb	Te
99.90 (min)	0.0005	0.0010	0.0025	0.0005	0.0650 (max)	0.0004	0.0002

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Figure 2. Soldered **s**amples in 20%NaOH corrosion test solution

Hence corrosion is a serious problem in soldering operations arising mainly from fluxes. In this study, samples obtained from UNS C 11040 quality copper electrical wire were soldered by three different types of soldering fluxes. Soldered samples corrosion resistance was tested by immersing in 20%NaOH solution for 96 hours of duration time. Samples weights were observed by a precision scale before and after the corrosion test for determining the weight losses related with corrosion resistance values [8]. A comparison is made for the corrosion rates of samples soldered by 3 different fluxes.

2. Materials and Methods

UNS C11040 type electrolytic copper wire is used in experimental studies. Copper wire samples have the dimensions of Ø3.5x10mm and given in Figure 1.

The copper wire chemical composition data obtained from the manufacturer according to the UNS C11040 document is given in Table 1. The outer plastic cover of the copper wire is removed and finally cleaned before the experimental operations.

Soldering method is applied by a hand soldering iron gun with an operating peak temperature of approximately 250°C. Solders chemical composition according to manufacturer data within ISO 9453 standard document is given in Table 2.

Three types of soldering fluxes were used in soldering operations. Soldering flux is applied before the melting operation of solder for efficient cleaning purposes. Soldering flux technical data are given in Table 3 according to the ISO 9454-1 standard [10]. Soldering fluxes are coded by 1, 2 and 3 instead of their original trade names.

Table 2. Chemical composition of solder wire [9]

Elements (by wt. %)		
Sn	Sb	Pb
62.5-63.5	0.20<	Balance

Table 3. Properties of soldering fluxes used in experimental studies.

	ISO 9454-1	
Flux Code	Ingredients	Condition
1	Zinc and Ammonium chlorides	Pasty
2	Amines and/or ammonia	Semi-solid
3	Resin with Halide activated	Pasty

Figure 1. Experimental electrical **c**opper wire

After the soldering operation, all samples were soft brushed and finally cleaned by pure water. Corrosion test is applied according to ASTM G1 standard document. All soldered samples including the unsoldered raw copper wire were subjected to 20% NaOH test solution with a duration time of 96 hours by holding separately in glasses. All of the samples were weighted by a precision electronic scale having accuracy of 0.0001g before and after the corrosion tests. Soldered samples in 20% NaOH corrosion test solution is given in Figure 2.

Corrosion rates of the samples were estimated by the Equation (1) as indicated in ASTM G1 Standard.

$$Corrosion\ Rate = [K \times W]/[A \times T \times D] \qquad (1)$$

K: $8.76x10^4$ (constant for $mm.year^{-1}$),
W: weight loss (g),
A: total surface area of samples (cm^2),
T: time (96 hours),
D: density (8.96 g/cm^3) in Equation 1.

Familiar types of corrosion testing methods such as potentiodynamic polarization, potentiostatic polarization and electrochemical impedance spectroscopy related with soldering have been reported [11]. Corrosion resistance of soldered samples can also be discussed by Energy dispersive spectrometry (EDS) and X-ray diffraction (XRD) methods [12-15]. Salt spray corrosion testing is also reported in soldering [16]. Testing at various corrosive ambient are announced [17]. But in this study corrosion resistance of soldered samples were determined by immersion into the test solution with weight loss principle.

3. Results and Discussion

3.1. Corrosion test results

Weights of soldered samples with raw copper wire before the corrosion test are given in Table 4. Weights of soldered samples with raw copper wire after the corrosion test are given in Table 5. Corrosion rates were estimated according to the weight losses via the Equation 1 and are given in Table 6.

Corrosion test results are graphically summarized in Figure 3. The highest corrosion rate (the least corrosion resistance) was determined on samples joined with Flux 3 while the least corrosion rate (the highest corrosion resistance) was detected on samples joined by Flux 1 as a result of Flux 3 containing halides. Raw copper electrical wire has also exhibited satisfactory corrosion resistance close to samples that joined with Flux 1 among the other types of joined samples. Samples soldered with Flux 2 exhibited also unsatisfactory corrosion resistance among all samples in consequence of having amines. These types of amine containing soldering fluxes have H, C, N, chlorides and bromides owing to make corrosion resistance become worse [6,7].

Table 4. Weights of soldered samples before the corrosion test.

Sample No.	Raw copper wire	Soldered sample with soldering Flux 1	Soldered sample with soldering Flux 2	Soldered sample with soldering Flux 3
1	0,5214	1,5593	2,0838	1,4387
2	0,5213	1,5593	2,0836	1,4385
3	0,5214	1,5592	2,0837	1,4386
Mean Values	*0,52136*	*1,55926*	*2,0837*	*1,4386*

Table 5. Weights of soldered samples after the corrosion test.

Sample No.	Raw copper wire	Soldered sample with soldering Flux 1	Soldered sample with soldering Flux 2	Soldered sample with soldering Flux 3
1	0,5208	1,5590	2,0754	1,4277
2	0,5209	1,5590	2,0753	1,4277
3	0,5208	1,5589	2,0754	1,4276
Mean Values	*0,52083*	*1,55896*	*2,07536*	*1,42766*

Table 6. Corrosion rates of samples

Solder Flux	Mean weights before the corrosion test (g)	Mean weights after the corrosion test (g)	Weight Loss (g)	Surface areas of samples (cm^2)	Corrosion rates (mm.year^{-1})
1	1.55930	1.55896	0.00034	1.290	$3.1x10^{-5}$
2	2.08370	2.07536	0.00834	1.290	$76.2x10^{-5}$
3	1.43860	1.42766	0.01094	1.290	$99.96x10^{-5}$
Raw Wire	0.52136	0.52083	0.00053	1.290	$4.84x10^{-5}$

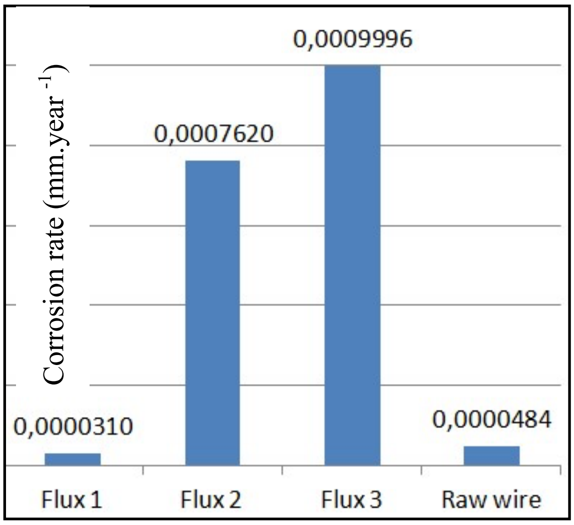

Figure 3. Corrosion test results

4. Conclusions

Corrosion test results revealed that corrosion resistance of copper based samples soldered with Flux types having halides exhibited the highest corrosion rate among all other two types of soldering fluxes. As halides are composed of salts the corrosion resistance is decreased.

The least corrosion rate is observed in samples soldered with zinc and ammonium chloride containing type Flux 1 soldering flux.

Whether corrosion resistance is a must in some copper bearing sensitive electronic or electrical component soldering operations, Flux 1 type zinc and ammonium chloride containing soldering fluxes can be preferred for safer joints.

Author contributions

A. B. Başyiğit: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing - original draft, Writing - review & editing

M. S. Ilıcan: Data curation, Formal analysis, Investigation, Resources, Supervision

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