Optimization of the electrical conductivity and tensile strength of conductive polymer composites using the Taguchi method

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Abstract. This research focused on optimization of the electrical conductivity and tensile strength of G5/G74/epoxy composites using the Taguchi method. Graphite with particle size of 5 µm (G5) and 74 µm (G74) were used as a second and as a main conductive filler. The mixing parameter used as control factor in Taguchi method are the composition of the second filler, mixing rotation, and mixing time. The Taguchi array with three mixing parameter were used in this research. The signal to noise (S/N) ratio was used to obtain the results of the research. The results of the research showed that the Taguchi method has succeeded in increasing the electrical conductivity and tensile strength of G5/G74/epoxy composites produced up to 18.28% and 18.42%, respectively.

1. Introduction
The conductive polymer composite (CPCs) material is potentially used as a material having high electrical conductivity and good mechanical properties. Compared to metals, this material is lighter, cheaper and has a better corrosion resistance, but it has a low electrical conductivity. To increase the electrical conductivity, a high content of conductive filler is required in the polymer matrix. On the other hand, the high content of the conductive filler material in matrix will also cause the poor mechanical properties of conductive polymer composites (CPCs) obtained [1-3]. Graphite is potentially used as a conductive material in a CPCs material, due to the high electrical conductivity, and it has various shapes and sizes. Beside that, this material is easily made by conventional processes such as casting or injection molding [4].

The Taguchi method is an effective method for obtaining optimum mixing parameters to produce a good properties of CPCs. This method can analyze each of the factors used [5]. The combination of the optimum factors was chosen based on the largest S/N ratio on all factors. Furthermore, the validity test on the best combination obtained was performed, to get the optimum results.

The optimum conditions for the electrical conductivity and tensile strength of the resulting material were obtained in separate studies [5, 6]. Therefore, it is necessary to optimize the electrical conductivity and tensile strength in one study by taking the highest S/N ratio value of each parameter value to obtain both desirable properties. Taguchi array L9 (3³) with nine samples used to obtain the optimum mixing parameters. Although nine experiments were the minimum number in the Taguchi array for three factors and three levels, but this minimum number was able to produce the optimum combination parameters [7-12]. Therefore, this study used the Taguchi array L9 (3³) for optimization of the electrical conductivity and tensile strength of conductive polymer composites.
2. Experimental

2.1. Materials
This research uses two conductive fillers of different size, i.e. graphite size 74 μm (G74) and graphite size 5 μm (G5). G74 is used as the main conductive filler while G5 is used as a second conductive filler. Both graphite materials are used in the form of flake. The gap formed from a larger conductive filler will be filled by a smaller conductive filler, so it is expected to increase the conductive network formed thus increasing the electrical conductivity produced. G74 was obtained from Asbury carbon, New Jersey while G5 was purchased from FRIway Industry, China. 635 thin epoxy resin obtained from the US Composites, with a viscosity of 6 Poise. The particle size and viscosity of the epoxy resin were obtained from the manufacturer.

2.2. Fabrication of G5/G74/epoxy composites
This research use G5 as a second filler (5, 7.5, 10 wt.%), G74 as a main filler (45, 42.5, 40 wt.%), and epoxy (50 wt.%) as the matrix. The fabrication process done by mixing epoxy resin and hardener using mechanical stirring machine (IKA RW 20 Digital) with mixing rotation of 25 rpm at 10 minutes. Next, the graphite (G5 and G74) at predefined composition is incorporated into the epoxy resin mixture based on control factor and level of mixing parameters used (see Table 1). Then the formed G5/G74/epoxy composites mixture is poured into the aluminum mold. Molds are inserted into the oven using a fixed temperature of 150 °C at 90 min.

2.3. Characterization
The electrical conductivity of G5/G74/epoxy composites with different composition of conductive fillers were measured by ASTM C 61 method [13]. Tensile strength of G5/G74/epoxy composites were measured using ASTM D3039. The scanning electron microscopy (SEM) of Hitachi S-3400 N used to observe the dispersion and voids of the conductive fillers within the polymer matrix through fractured surfaces of G5/G74/epoxy composites.

2.4. Selection of Control Factors
The Taguchi Method used on this study, to optimize control parameters to get the best results through the Design of Experiments of orthogonal array. The orthogonal arrays (OA) provide a set of well balanced (minimum) experiments and signal to noise ratios (S/N), help in data analysis and prediction of optimum results. The control factors of mixing parameter are composition of the second filler, mixing rotation, and mixing time. Table 1 show the three control factors with three levels of mixing parameters.

| Symbol | Control Factors                  | Unit   | Level |
|--------|----------------------------------|--------|-------|
| Acf    | Composition of second filler     | wt.%   | 5     |
| Bmr    | Mixing rotation                  | rpm    | 30 50 |
| Cmt    | Mixing time                      | Minutes| 15 25 |

3. Research and Discussion

3.1. Characterization of conductive fillers
Figure 1 shows the conductive filler type used to produce a G5/G74/epoxy composites material. Scanning Electron Microscopic (SEM) images shows that G74 as the main conductive filler and G5 as the second filler filler have the different size and same shape (flake shape).
3.2. The electrical conductivity of G5/G74/epoxy composites of the mixing parameters

The electrical conductivity of G5/G74/epoxy composites on each experiment based on the Taguchi array L9 (3^3) that has been performed is shown in Table 2. The lowest electrical conductivity of G5/G74/epoxy composites was obtained on the experiment 2 (0.3 S/m), while the highest value was on the experiment 7 (3.80 S/cm). From this condition, it can be seen that the weight percentage (wt. %) of the second filler, mixing rotation and mixing time are effective influence the electrical conductivity of G5/G74/epoxy composites.

Table 2. The Electrical Conductivity Of G5/G74/Epoxy Composites Based On Taguchi Array L9 (33)

| Experiment | Control Factors and Levels | Electrical conductivity (S/m) |
|------------|----------------------------|-------------------------------|
|            | A_cf (wt.%) | B_mr (rpm) | C_mt (minutes) |            |
| 1          | 10          | 30          | 15              | 2.90       |
| 2          | 10          | 50          | 25              | 0.30       |
| 3          | 10          | 70          | 35              | 3.05       |
| 4          | 7.5         | 50          | 15              | 2.60       |
| 5          | 7.5         | 70          | 25              | 0.70       |
| 6          | 7.5         | 30          | 35              | 2.70       |
| 7          | 5           | 70          | 15              | 3.80       |
| 8          | 5           | 30          | 25              | 2.80       |
| 9          | 5           | 50          | 35              | 3.35       |

3.3. Taguchi response to the electrical conductivity in mixing parameters

Figure 2. Shows S/N ratio of mixing parameters comprising of second filler composition, mixing rotation; and mixing time. Based on the desired S/N ratio of the larger the better, then the optimum mixing parameter of G5/G74/epoxy composites obtained was at A₃ (5 wt.% second fillers), B₁ (30 rpm mixing rotation), and C₃ (35 minutes mixing time). The results show that high content of second conductive filler and high mixing rotation is not required to get the high electrical conductivity of G5/G74/Epoxy composites. The high content of the second conductive filler in the matrix will cause the number of voids to occur, so that the conductive filler is not well dispersed, thus causing in low electrical conductivity of G5/G74/Epoxy composites. Similarly, high rotational mixing will damage the conductive network formed, thereby lowering the electrical conductivity [14, 1]
Figure 2. S/N ratio of G5/G74/epoxy composites materials to the mixing parameters

3.4. The electrical conductivity and tensile strength based on recommendation of Taguchi method

The recomended optimum parameters of the electrical conductivity based on S/N ratio of G5/G74/epoxy composites to mixing parameters were used to produce the G5/G74/epoxy composites new specimen. At this stage, the electrical conductivity and tensile strength were measure to see how effective the Taguchi array L9 (3^3) to increase the electrical conductivity and tensile strength of G5/G74/epoxy composites. The results show that the specimen produced based on Taguchi recommendation has a better properties of the electrical conductivity and tensile strength compared to the value obtained in the experiment 1 of mixing parameters (see Table 3).

Table 3. Optimization Of The Electrical Conductivity And Tensile Strength Using Mixing Parameters Based On The Taguchi Array L9 (3^3) Recommendation

| No | CPCs material | Electrical Conductivity (S/m) | Tensile Strength (N/mm^2) |
|----|--------------|------------------------------|--------------------------|
| 1  | Experiment 1 | 2,90                         | 123,8                    |
| 2  | Taguchi recomendation | 3,43                        | 146,6                    |

The dispersion of the conductive fillers within polymer matrix were greatly determines the electrical conductivity of G5/G74/epoxy composites [14, 2]. Figure 3. shows scanning electron microscopic (SEM) images of fractured surface of G5/G74/epoxy composites. The conductive fillers in the polymer matrix (epoxy resin) of Taguchi recomendation (Figure 3.b) were dispersed better, compared than the G5/G74/epoxy composites material produced on the experiment 1 (Figure.3a). As well as voids, which were successfully reduced by using the recomended parameters of the Taguchi method. This condition generate a better electrical conductivity and tensile strength of G5/G74/epoxy composites (see figure 3) [15]

Figure 3. SEM images of fracture surface of G5/G74/epoxy composites (a) Experiment 1, (b) Taguchi recomendation
4. Conclusion
Taguchi Method has been used to optimize mixing parameters to obtain better electrical conductivity and tensile strength for G5/G74/epoxy composites. The conclusions can be summarized as follows:

1. The Taguchi array of L9 (3^3) is able to optimize the optimum parameters to increases the electrical conductivity and tensile strength of resulting G5/G74/epoxy composites material effectively.
2. The optimum parameter for the electrical conductivity and tensile strength is on combination of A3 (5 wt.% second fillers), B3 (30 rpm mixing rotation), and C3 (35 minutes mixing time).
3. The electrical conductivity and tensile strength of G5/G74/epoxy composites material produced are successfully increase from 2.9 S/cm to 3.43 S/cm (18.28 %), and from 123.8 N/mm² to 146.6 N/mm² (18.42 %) respectively.

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