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The Application of Taguchi Method in Optimizing Fabrication of Composite Panel for Particleboard

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Abstract: ***This paper titled The Taguchi Method application for mechanical properties in the making of particleboard was one by considering the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) as a testing parameter. This research was done by using combination of dust wood and fruit from Acacia itself as main materials. It was mixed with Polyurethane (PU) as a resin and Paraffin Wax (PW) as a filler with specific values. This study mainly uses Hot Press Machine (HPM) and the Universal Tensile Machine (UTM) to produce and test specimens. The TGA analysis was used to prove the indicator of temperature before the process of the specimen began. Meanwhile the SEM and EDX testing were used to identify spectrum of chemical content in the specimen after the testing process was done. The Taguchi Method is used to create the design of experiment (DOE) table that contains optimized parameter of experimental results. While to foresee the degree of centrality tests that add to the solidarity of the quality is finished by ANOVA with Minitab 17 programming. The result will be compared with the Japanese Industry Standard (JIS) for MOE and MOR testing. From the research, the optimized formula was A3B3 specimen. The results obtained for MOE was 5134 (MPa) for Modulus Young and the result of MOR was 21.9 (MPa) for Flexural Strength.***

Keywords: Homogeneous particle board, palm oil fiber

I. INTRODUCTION

Nowadays, the manufacturing industries are looking forward to produce high quality product with minimal cost [1]. to get a product with these characteristics, these manufacturers must have the best formula as a reference [2] in the making of the product. The formula must have a good value of modulus young and flexural strength. At the same time, the selected of material sizes, types of resin, additive as a filler, parameters and indicators must be accurate in order to avoid wastage which can increase the cost of money, time and energy to the industry itself. Therefore, the purpose of this study is to determine the optimum value in the making of particleboard by using the Taguchi Method application. The appropriate parameters also will be produced for HPM process and UTM testing used. The DOE was design by Taguchi method [3] while the analysis result of data was carried out by using ANOVA through Minitab 17 software.

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II. MATERIAL AND METHOD

A. Materials

The choice of Acacia tree as a fiber material in this exploration is to lessen the forestation exercises. Right now, Acacia trees are seen uncontrollably developing in Peninsular Malaysia however left relinquished. By utilizing the waste, for example, the parts of Acacia tree, it will build the estimation of this species and evade the air contamination due to open consuming exercises [4]. Every one of the segments in the Table I is the primary factors really taking shape of molecule board.

Table I: List of materials used (Particleboard)

List of components	Types of item used
Fiber/Particle	Acacia tree and Fruit of Acacia
Resins	Polyurethane (PU) adhesive
Filler	Paraffin Wax (PW)

B. The Pre-Treatment Process

The foods grown from the ground wood pieces of Acacia tree were washed with faucet water to expel any unused, trash from cutting procedure, earth and undesired substances. After that it was dried at an atmospheric temperature range between 28 °C to 30^{0}C prior to next treatment process. After that it was treated with sodium hydroxide (NaOH) solution at 8% by volume of clean water [5]. This process was continued by soaking these materials in NaOH solution for 3 hours at room temperature. After that it was washed twice or more with distilled water to allow absorbed alkali to leach from the material content. The fruit and the branches of Acacia tree were dried in an oven maintained at 80°C with ±5^{0}C [1]. This process was kept ongoing until the Moisture Content (MC) of the material achieved % to 13% [6] of the temperature value prospect as what JIS needs before proceeding to the next process.

In other literature, it was said this procedure is done to lose the cellulose structure, producing a halfway structure being changed over to a carbonized fiber empowering simpler assimilation of the pitches for the following procedure. The absorption shown that the NaOH treatment played a positive role in forming of specimen and reaction of resins process [7]. During the process, the dried of products of the soil parts of Acacia tree were put away in a fixed plastic pack to stay away from climatic dampness tainting preceding the granulating procedure to get the residue from both of material. This is to control the MC of the material.

C. Preparation of Acacia Sawdust (Fruit and branches)

The branches and fruit of Acacia tree as shown in Fig. 1 was grinded using grinding ball machine type Pulverisette 7 from FRITSCH Model to get uniform size of particle. The sizes of particles are in the range of 4mm>x>2mm [9]. After sieving process, the particles were dried once again in an oven for 48 hours at 80^0C±5^0C to obtain between 5% to 13% of moisture content [7] prior to the fabrication process [2].

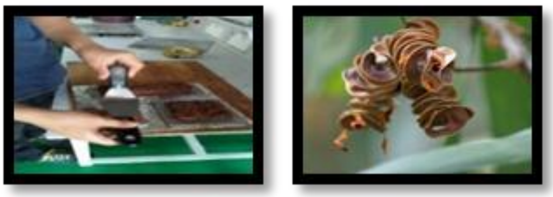

Fig 1: Acacia Tree and Fruit of Acacia

D. Production of Particleboards

In the manufacturing of particleboard, polyurethane (PU) adhesive was used as main resin. Three different sizes of specimen were used and the target density (750kg/m^3) was set at medium density (400 kg/m^3 to 900 kg/m^3) range according to JIS [7].

The percentage of filler was fixed to 0%, 10% and 20%. The combination of material between dust of fruit and dust of Acacia tree was fixed to ratio 50:50. These conditions are believed to be capable in increasing the mechanical properties of particleboard [10]. The preparation of the board specimens in this research depended on the required weight fraction and sieving size. The processing parameters used in the particleboards production are shown in *Table II*.

Table II: Parameters for particleboard production

Parameter	Details
Target density (kg/m^3)	750
Pressure Time (min)	5
Pressure (bar)	160
Temperature (^{0}C)	120

The desired density for the research was 750 kg/m^3. It was in the range of medium density (400 kg/m^3 to 900 kg/m^3) by following the Japanese Industry Standard (JIS). This selection of range density was believed can reduce the particleboard manufacturing cost but still can produce the strongest particleboard. The Pressure of time in the research was 5 minute [11]. The pressure was 160 (bar) and it was set by referring to the previous experiment and others researcher [2] [11]. Figure 6 shows the TGA result that the material starts to decompose after 237°C and the PU starts to cure after 120°C [12].

At the same time, certain polymeric of waxes such as PW may require over the temperature range of 0-130 °C to analyze. Some of them also required a higher upper temperature limit (150°C -170°C), this is in order to obtain a complete melting profile [13]. Because of that the value of 120°C was the optimum temperature in the making of particleboard by considering the PU peak curing temperature at 120°C, the material started to decompose and the higher upper temperature limit of PW. *Table III* shows the dimensions of specimen and their types of testing [7].

Table III: Dimension of Particleboard

Types of Testing	Dimension
MOR and MOE	200mm x 50mm x 10mm

The formulations of particleboard are indicated in Table IV. The PU adhesive was prepared by reacting the isocyanate and palm kernel oil based polyol with a ratio of 1:1, 1:1.5 and 1:2. Meanwhile, the weight of combination between dust wood of Acacia and the fruit of Acacia was calculated by using (1):

$$\rho = m/v \quad (1)$$

The particles (Acacia and the fruit) were blended with PU adhesive and filler (PW) and the mixture was stirred until it well blended by using the optimization formula from table DOE created earlier by Taguchi Method. Then the mixture was put into the mold and pressed using a Hot Press Machine for 5 minutes [2] at 160^0C. Nine specimens for each MOE and MOR were created using mixed hardwood species by cutting them into specific structure according to JIS. The specimens' density ranges from 400 kg/m3 to 900 kg/m3 were processed into standard sizes, 200mm × 50mm × 10mm (2 × 2 × 30 inches). The modulus of rupture (MOR) was calculated by using (2):

$$MOR_{sc} = \frac{3PL}{2bd^2}, \quad (2)$$

where P = applied load (N), L = span (mm), b = width (mm) of the specimen and d = depth (mm) of the specimen. Modulus of elasticity (MOE) was calculated by using (3):

$$MOE_{sc} = \frac{1}{4} \times \frac{P'L^3}{\Delta' bd^3}, \quad (3)$$

where P = applied load at the limit of proportionality (N), L = span (mm), Δ' = deflection at the limit of proportionality (mm), b = width (mm) of the specimen and d = depth (mm) of the specimen. The local modulus of elasticity was calculated by using (4):

$$MOE_{f,local} = \frac{a l_1^2 \Delta F}{16 I \Delta w}, \quad (4)$$

where a = distance (mm) between a loading point and the nearest support, l1 = gauge length (mm), I = second moment of area (mm4), ΔF = increment of load (N) and Δ_w = increment of deformation (mm) corresponding to ΔF. The deflection for local MOE was measured on one side of the specimen. The modulus of elasticity was calculated by using (5):

$$MOE_{f,global} = \frac{l^3 \Delta F}{b h^3 \Delta w}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right], \quad (5)$$

where a = distance (mm) between a loading point and the nearest support, l = bending span (mm), b = width (mm) of the specimen, h = depth (mm) of the specimen, ΔF = increment of load (N) and Δ_w = increment of deformation corresponding to ΔF (mm). The modulus of rupture (MOR) was calculated by using (6):

$$MOR_f = \frac{F_{max} a}{2W}, \quad (6)$$

where F_{max} = maximum load (N), a = distance (mm) between an inner load point and the nearest support and W = section modulus (mm3). A small portion was cut from every specimen for the determination of wood density. The density of specimen at test was calculated from the equation (7) where ρ_{test} = density (kg/m3) at test, m = mass (kg) at test and V = volume (mm3) at test.

$$\rho_{test} = \frac{m}{V}, \quad (7)$$

E. Design of Experiment (DOE) and Main Effects Plots (MEP)

During the research, the Taguchi Method software was used to create a Design of Experiment (DOE) table. Meanwhile to predict the level of significance tests that contribute to the unity of the strength is done by ANOVA with Minitab 17 software. The Taguchi method used 3 level designs for table type of design.

There are two (2) contributing factors in this research, which are Isocyanine and PW. Meanwhile the display available for Taguchi Designs (With number factor) for single level design was set for L9 and 3-level with indicator 2-4. Here, the Taguchi Design column was run at L9 and the 3^2. After that the Taguchi Design factor column was assign with name of factor as A and B (an Isocyanine and PW) and the level of level value column was set name as 1,2 and 3 (refer to the picture of flow chart).

The DOE from Taguchi Method is important to get the Optimization Formula. The table below is the DOE table created by using Taguchi Method software.

Table IV : Design of Experiment (DOE)

Session

```
L9(3^2)

Factors:  2
Runs:     9

Columns of L9(3^4) Array

1 2
```

Worksheet 1 ***

↓	C1 A	C2 B	C3 MOE	C4 MOR
1	1	1		
2	1	2		
3	1	3		
4	2	1		
5	2	2		
6	2	3		
7	3	1		
8	3	2		
9	3	3		

Meanwhile, the ANOVA with Minitab 17 software was set with Main Effects Plots (MEP) to get the multi response result to obtain the optimization parameter. Here, the mean data were plotted for each level of one or more factors to examine how the factors influence the response. The Fig. 2 shows the table of MEP.

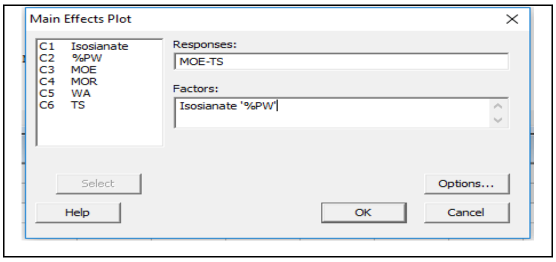

Fig 2: Main Effects Plots (MEP)

III. RESULT AND DISCUSSION

A. The Taguchi Method Analysis

Table IV shows that Taguchi Method software only presents two factors set when in fact this research propose four factors. They are size of material, Polyol, Isocyanate and PW. However, based on the result from the previous research, [9] the best size of material in the making of the particleboard was 2mm<x<4mm. The same goes to the Polyol, it was set as a constant value. In this research the weight of 45g based on the ratio (Polyol: Isocyanate) 1:1, 1:5 and 1:2 Became the main reference. Due to this, there are only two factors left to be put into DOE in the Taguchi Method. They are Isocyanate and PW.

Table V: DOE and Result of Response

	A	B	MOE	MOR
1	1	1	3761.82	13.60
2	1	2	3898.99	15.20
3	1	3	6249.63	15.40
4	2	1	4979.92	21.10
5	2	2	4406.42	8.32
6	2	3	4942.20	23.60
7	3	1	4891.94	23.10
8	3	2	6572.99	20.80
9	3	3	5134.10	21.90

Nine optimization formulas were created by DOE formula and were tested to the two responses, MOE and MOR result only. The table below shows the result of the DOE process.

B. The Result of MOE

Table VI shows the 9 results of specimen for modulus young [MPa] during the Modulus of Elasticity (MOE) testing. The lower value was specimen no.1 with 3761.816 MPa as the result. Meanwhile the higher value was the specimen no.9 with 6572.995 MPa as the result. The mean value for 9 specimens was 4982.002 MPa and the maximum load for mean [kN] was 1.658. This result proved that the JIS requirements for MOE testing have been successfully achieved [7].

Table VI : Result MOE by Using Universal Tensile Machine (UTM)

	Time at Break (Standard) [s]	Load at Break (Standard) [kN]	Maximum Load [kN]	Modulus (Automatic Young's) [MPa]	Extension at Yield (Offset 0.2 %) [mm]
1	60.400	-0.285	0.617	3761.816	0.383
2	60.614	-0.164	1.026	4406.421	0.451
3	7.700	2.971	2.971	5134.101	0.872
4	66.800	0.378	0.962	3898.994	0.328
5	60.400	-0.219	1.048	4942.200	0.472
6	6.000	2.739	2.739	4891.941	0.827
7	4.600	2.185	2.308	6249.629	0.649
8	60.854	-0.330	1.033	4979.921	0.467
9	16.900	1.196	2.216	6572.995	0.574
Mean	38.252	0.941	1.658	4982.002	0.558
Median	60.400	0.378	1.048	4942.200	0.472
Maximum	66.800	2.971	2.971	6572.995	0.872
Minimum	4.600	-0.330	0.617	3761.816	0.328

C. The Result of MOR

Table VII describes the details in procedure B with 160 mm support span. The span-to-depth ratio was 16:1 and the support radii (mm) was 3:2. It was same goes to the Loading radius (mm) with ration 3:2. The rate 1 with 42.67000 mm/min was use as a speed process during the testing. All the indicator comply with the ASTM D 790-10 (Standard Test Method for Flexural Properties of Dust Wood and Fruit of Acacia).

Table VII: Basic parameter for MOR testing

ASTM D 790-10 Standard Test Method for Flexural Properties of Dust Wood of Acacia and Fruit of Acacia

Direction cutting/loading	
Conditioning procedure	
Procedure	B
Support span	160.00000 mm
Span-to-depth ratio	16:1
Support radii (mm)	3.2
Loading radius (mm)	3.2
Rate 1	42.67000 mm/min
Span ratio	2

Table VIII shows the result of MOR by using the Universal Tensile Machine (UTM). The 9 specimens were tested. Specimen no. 5 shows the lowest result with 8.32 MPa of flexural strength. It gives out 0.45197% of Flexural Strain. Meanwhile the higher result was specimen no 9 with 21.9 MPa. It gives out 0.76244 % of Flexural Strain. The mean result of the test was 18.1 MPa with 0.70396 % of Flexural Strain. The Standard Deviation was 5.2 MPa and the Flexural Strain was 0.16%.

Table VIII: Result MOR by Using Universal Tensile Machine (UTM)

	Width [mm]	Depth [mm]	Flexural Strength [MPa]	Flexural Stress at Break [MPa]	Stress at 5% Strain [MPa]	Flexural Strain [%]	Tangent Modulus (1%) [MPa]	Secant Modulus (1%) [MPa]	Chord Modulus (0.5% - 1.0%) [MPa]	Flexural Offset Yield Strength (0.2%) [MPa]	Specimen behavior
1	50.0	10.0	13.6	0.88619	-----	0.94203	2140	1350	1100	-----	Rupture
2	50.0	10.0	15.2	1.10	-----	0.78200	1830	282	-1430	-----	Rupture
3	50.0	10.0	15.4	1.75	-----	0.74244	3030	442	-1200	-----	Rupture
4	50.0	10.0	21.1	0.83020	-----	0.52862	4590	272	-3430	-----	Rupture
5	50.0	10.0	8.32	0.62338	-----	0.45197	-362	328	-872	-----	Rupture
6	50.0	10.0	23.6	1.06	-----	0.59543	5240	328	-3340	-----	Rupture
7	50.0	10.0	23.1	1.26	-----	0.85204	3280	1700	320	-----	Rupture
8	50.0	10.0	20.8	1.27	-----	0.67868	4600	494	-2640	-----	Rupture
9	50.0	10.0	21.9	0.78924	-----	0.76244	3730	384	-2260	-----	Rupture
Mean	50.0	10.0	18.1	1.06	-----	0.70396	3120	620	-1530	-----	
S.D.	0.00	0.00	5.20	0.34	-----	0.16	1732.85	525.88	1564.23	-----	

D. TGA Specimen Testing Result

The TGA testing was done by using the specimen with A3B3 formula. During this experiment, the range of temperature was set to the 900°C. It was dynamic scan with 10 °C per minute as a setting. The graph shows that the specimen started to decompose at 237°C and reduces at 389°C. The result concluded the best temperature in the making of the particleboard was below the 237°C. A temperature higher than that will reduce the weight of the specimen and significantly affect the density and strength of the specimen [2].

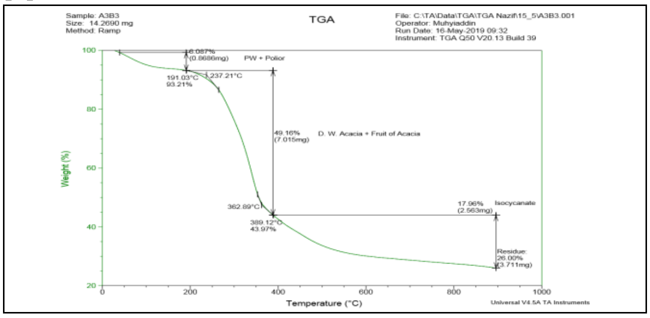

Fig 3: TGA Result for A3B3

E. SEM and EDX Specimen Testing Result

The SEM is the process to identify the molecule of the specimen. Meanwhile the EDX is the process to identify the chemical content of the specimen. Fig 4 shows the spectrum of Nitrogen, Oxygen, Hydrogen and Carbon in the specimen. A composite must possess a spectrum of Oxygen and Carbon content. The figure proves that the specimen is indeed a composite specimen as it shows the spectrum of Oxygen and Carbon it contains [12]. At the same time, the Nitrogen spectrum proves that element of PU exists in the specimen. However, due to its characteristic of being light molecule, Hydrogen spectrum does not appear on the result screen.

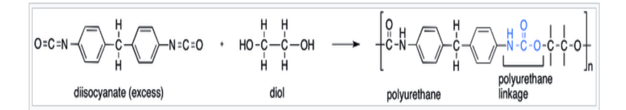

Fig 4: Synthesis of Polyurethane from a di isocyanides and a diol

Fig 5 shows he picture of the specimen by using the SEM. It has gone through a zooming of 1756 times. The result shows the specimen has spectrum of Carbon, Nitrogen and Oxygen. The value of the Carbon was 64.38%, Nitrogen 1.91% and Oxygen was 33.71%. These molecular contents show that this research is a polymer research with the presence of Carbon, Nitrogen and Oxygen. The high Carbon content proves that this particleboard specimen has a great potential to produce high quality furniture's.

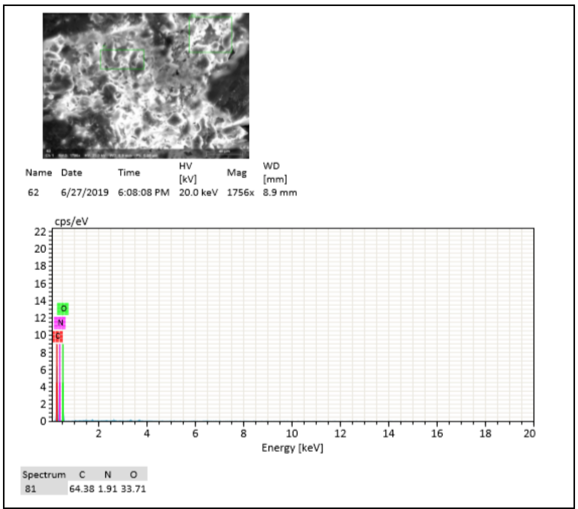

Fig 5: SEM and EDX Result

F. The Taguchi Method Analysis

Taguchi Method applies he indicator "Bigger is better" by using Analyze Taguchi Design to analyze the MOE and MOR result. Fig 6 and Fig 7 respectively show the "Main Effects Plot for Means" and "Main Effects Plot for SN Ratios" with A3B3 as the best finding for MOE and MOR testing. This is also used as an indicator to prove that increment in PW and hardener will significantly affect the strength of the material [13].

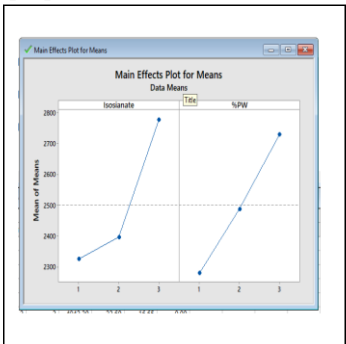

Fig 6: Graph for Min

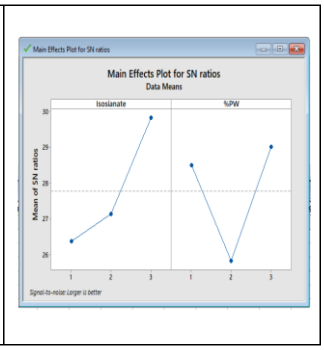

Fig 7: Graph for SN Ratio

G. ANOVA with Minitab 17 software with Main Effects Plots (MEP) Analysis

The use of ANOVA with Minitab 17 with 'Main Effects Plot (MEP) analysis is to prove the result from the Taguchi Method software. "Main Effects Plot for MOE" (Fig 8) and "Main Effects Plot for MOR" (Fig 9) once again show A3B3 as the best result. The result obtained from this research aligns with the result obtained from Taguchi Method. This proves that both analysis are consistent and significant.

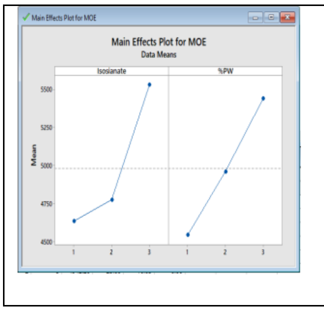

Fig 8: Main Effects Plot for MOE (Data Means)

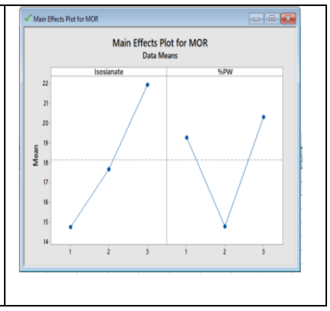

Fig 9: Main Effects for MOR (Data Means)

IV. CONCLUSION AND SUGGESTION

The research and tests conducted has produced an optimization formula, the A3B3 formula. his formula was the best combination of all elements (material, resins, hardener and the filler) in the making of homogenous particleboard for manufacturing industries. This result is a well approved decision from the analysis done using the Taguchi Method software through single respond analysis for "Bigger is better" and it is supported with ANOVA software showing the same result. For future research, a run on the conformation test (A3B3) will be done to obtain optimization parameter. At the same time, the SPSS software will be used to produce the mathematical model and to see the most significant factor in the research. Three specimens must be produced by using the Hot Press Machine and it must be tested by going through the same procedure as the Taguchi Method process. The specimens also have to be tested by using the TGA, SEM, EDX and FTIR testing (extra testing procedure). The result from the conformation test will be the support indicator to produce the homogenous particleboard from the Acacia species product in the future.

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His research interests centre on promoting green manufacturing practices through powder metallurgy field, principally through the synthesis and characterization of porous metallic biomaterials, Bio-functionalizing coatings, and mechanics of biomaterials mainly using laser fusion techniques and metal/polymer injection moulding process. He has published more than 40 papers in journals and conferences. He also actively involves in domestic and international professional bodies such as Board of Engineers Malaysia (BEM), Institute of Engineer Malaysia (IEM), Malaysian Powder Metallurgy and Particulate Materials Association (MPM2A), Japan Society of Powder and Powder Metallurgy (JSPM), Society of Manufacturing Engineer (SME), and American Powder Metallurgy International (APMI).