OPTIMIZATION OF SINGLE POINT INCREMENTAL FORMING (SPIF) PROCESS PARAMTERS ON SPRINGBACK OF DISSIMILAR FRICTION STIR WELDED ALUMINIUM ALLOYS BLANK USING TAGUCHI METHOD

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ABSTRACT: Single-point incremental forming (SPIF) is a die-free sheet metal-forming approach where various profiles can be produced distinctively. However, geometrical defects such as a springback occur during the process and are difficult to control, hence causing assembly errors. This issue becomes more critical for sheets that consist of dissimilar metal joints joined together using the friction stir welding process. This paper investigated the effect of single-point incremental forming (SPIF) parameters such as rotational speed, feed rate, step size, and wall angles on the springback. In this study, a truncated cone profile made of AA 6061 and AA 5052 was studied. The Taguchi method was utilised to identify the most significant effects and optimal SPIF process parameters. The results showed that the wall angle had the most significant effect on the springback compared to others. Based on the ANOVA, the percentage contribution of wall angle was the highest for both sides, which are 93.63% and 89.68%, respectively, compared to other parameters.

KEYWORDS: *Springback; Single Point Incremental Forming; Friction Stir Welding; Dissimilar Alloys and Taguchi Method*

1.0 INTRODUCTION

Recently, demands for light and stronger materials that are easy to form are increasing, and one of the methods is by joining dissimilar materials that, when combined, can possess all the required properties [1], [2]. In general, aluminium alloys are the best candidates, but unfortunately, some of them are relatively expensive. Therefore, an approach in joining two types of aluminium alloys to compromise their properties nowadays has become a trend [3]. For example, in aluminium alloys, 5xxx is commonly used for automotive inner body panels, while 6xxx is commonly used for exterior body panels [4]. Applications such as deck lids, hoods, floor and door inner panels, side frame rails, and others from aluminium TWBs can be found elsewhere [5], [6].

Single-point incremental forming (SPIF) is a low-cost, die-less, and higher flexibility process in the sheet metal forming process [7], [8], [9]. SPIF often combines spinning and shear forming [10]. In comparison to the conventional stretch flanging procedure, the researchers' investigation showed that the SPIF approach is more flexible and efficient [11], [12]. This method is particularly useful for rapid prototyping and low-volume production [13], [14]. In the process, the sheet is gradually shaped into the required shape by a tool moving along a predetermined path [15], [16]. Therefore, one of the main problems with SPIF is dimensional accuracy [17], [18]. There are three types of errors that lead to geometric inaccuracies in SPIF processes: unwanted sheet bending occurs over the backing plate of the clamping fixture, at the upper corner radius area, and then very near the main base of the part. Another dominant defect is the springback, which can be described as an elastic phenomenon that occurs in practically all curved sheet metal parts [19]. Lastly, the pillow effect is a concave surface that occurs on the bottom of the part, which is an under-formed area. These defects are as illustrated in Figure 1.

The SPIF can be assessed based on springback [4], [21], formability [22], surface roughness [23], and forming time [24]. Geometrical accuracy due to springback has an undesirable effect on this process since the sheet material is attached to the clamped die-less frame [25]. Springback still remains a major issue in the fabrication of any finished product within the allowable tolerance in sheet metal forming [26].

There are a few studies in SPIF on the relationship between the process parameter and springback.

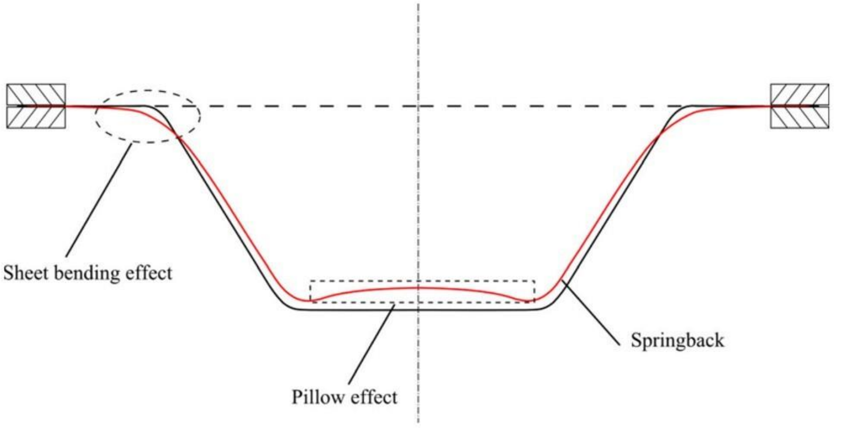


Figure 1: The common types of error found in parts produced by single-point incremental forming (SPIF) [20].

Table 1 summarises the studies. Based on the studies, step size was found to have the most influence on process parameters. Note that Taguchi Method and ANOVA is among the popular tools [27], [28]. Other process parameters, including rotational speed and wall angle, were considered [29]. There are also studies on the effect of tool path on the springback pattern [30]. However, based on the literature, it was observed that there is not much study on the springback pattern of dissimilar material. Therefore, the objective of the paper is to study the effect of those parameters in the SPIF process on the springback using the Taguchi method and ANOVA.

Table 1: Recent studies on the SPIF process parameter and their effect to the springback pattern.

References	Parameter studies	Method	Findings
Zhang et al., (2018) [31]	Increment step and stamping location	Neural Network	The nearer the location of stamping, the lesser springback occurs. While increment step has less effect to the springback.
Patel et., (2020) [32]	Wall angle, feed rate and step size	Experiment	The wall angle primarily causes the springback, while the feed rate has the least effect

Mezher et al., (2021) [33]	Step size and forming depth.	Simulation and Experiment	Increasing the wall angle results in an increase in the degree of springback.
Honarpisheh et al., (2019) [34]	Rotational speed, feeding rate, and vertical step parameters	Experiment	All parameters affect the springback formation.

2.0 MATERIALS AND METHODS

2.1 Materials

There are two materials involve in the study, AA 5052 and AA 6061 with same thickness 1.5 mm. Sheets with dimensions of 80 mm x 200 mm for each material were butt-joint using friction stir welding (FSW) process. The process can be illustrated as in Figure 2. The tools are made of H13 hot working steel with non-threaded 1mm length and diameter 5mm of cylindrical pin and have been heat treated to 58 HRC.

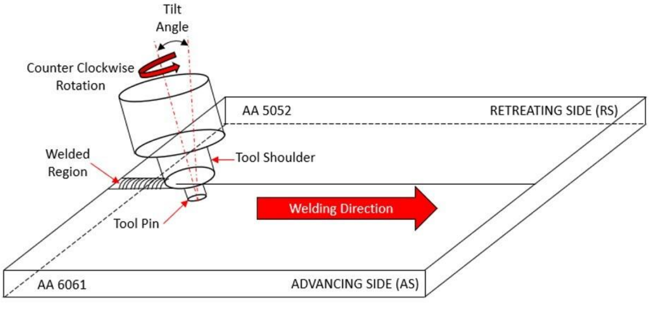


Figure 2: Illustration of FSW process and specimen setup

2.2 Design of Experiment

Four parameters make up the experiment design, as shown in Table 2: rotating speed, feed rate, step size, and wall angle. Each of these parameters has three levels. Based on the literature review that was covered in the preceding part, the range of each parameter was taken into consideration. The conical form profile made up of two different materials is depicted in Figure 3. Angle: The angle at the AA 6061 side is denoted by α, and the angle at the AA 5052 side by β.

Table 2: SPIF process parameters and levels

Factors	Units	Levels		
		1	2	3
Rotational Speed	RPM	1250	1500	1750
Feed Rate	mm/min	800	900	1000
Step size	mm	0.2	0.3	0.4
Wall Angle	°	55	60	65

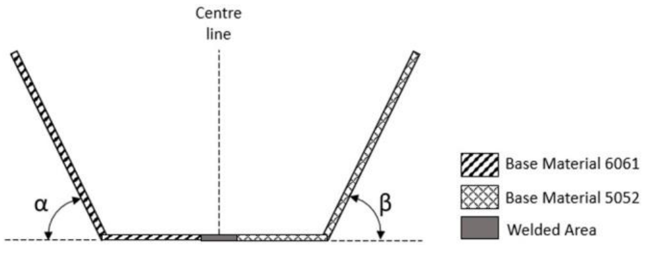
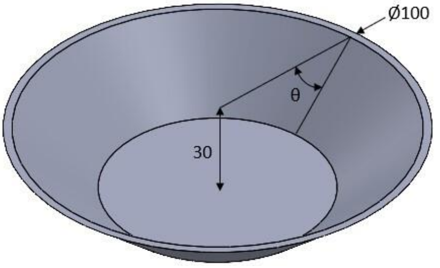


Figure 3: Illustration of measurement sections on formed dissimilar material of TWBs

2.3 Single Point Incremental Forming

The profile of the conical shape was generated by MasterCAM software. The geometries of the profile consist of an opening diameter of 100 mm, a forming depth of 30 mm, and a varied wall angle, θ, which is 55°, 60°, and 65°. The incremental forming path with the tool swept a true spiral path, gradually moving downwards and towards the centre until it finished. The conical parts were formed using a SPIF forming tool made of high-speed steel with a hemispherical tip and a nose diameter of 12 mm. Lubricant SAE 40 was applied during the process. The process shown in Figure 4 is carried out on a DMG MORI 5-axis milling machine equipped with a Siemens D810 controller.



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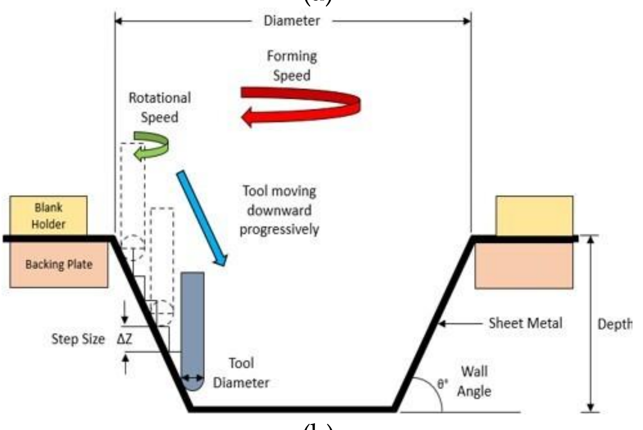

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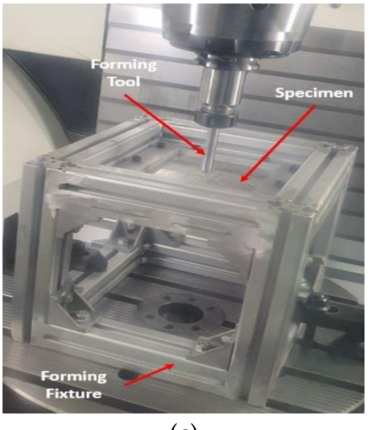

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Figure 4: (a) CAD design of experiment, (b) Illustration of SPIF working principle and (c) Location of FSWed blanks on forming fixture in 5-axis CNC machine

2.4 Springback Measurement

A Coordinate Measurement Machine (CMM) (Mitutoyo Crysta-Plus M443) was used to measure the profile of the formed part at 10 marked points on both sides, as shown in Figure 5. The measurement has been made twice for each side and the average angle will be calculated by using

$$\alpha_{avg} = \frac{\alpha_1+\alpha_2+\cdots+\alpha_n}{n} \quad \text{and} \quad \beta_{avg} = \frac{\beta_1+\beta_2+\cdots+\beta_n}{n} \qquad (1)$$

Where α_{avg} represent the average angle on AA 6061 side, β_{avg} represent the average angle on AA 5052 side and n is the number of marking point.

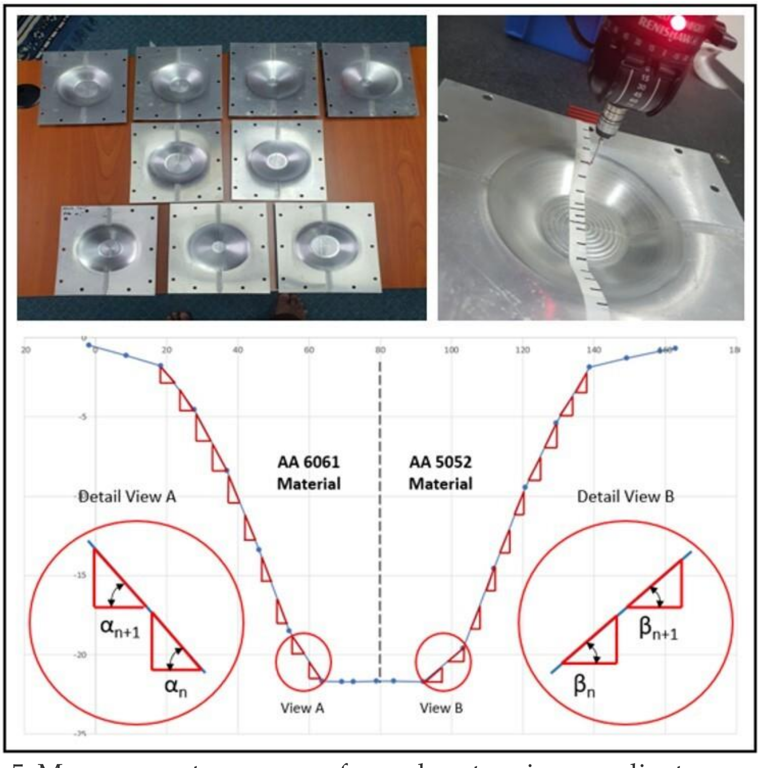


Figure 5: Measurement process on formed parts using coordinate measuring machine (CMM)

Local deformation is caused along the path surrounding the contact area by the movement of the forming tool. Consequently, there is constant local cumulative deformation, and residual tension causes springback when the forming tool is retracted. As demonstrated in Figure 6, the wall cross-section, αt is the wall angle derived from a CAD model, αavg is the average angle following SPIF, and δ is the difference between αt and αavg, which denotes the springback. The solid line represents the incremental sheet forming target profile, and the dotted line represents the actual shape after springback. Equation (2) illustrates how springback is measured following the SPIF procedure.

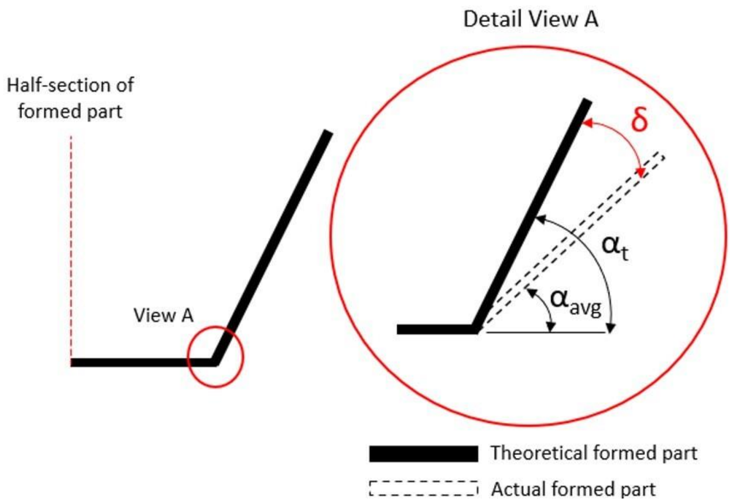


Figure 6: Schematic diagram of springback on formed part

$$\delta = \left|\alpha_{avg} - \alpha_t\right| \quad (2)$$

Where δ is the value of Springback (δα refer AA 6061 side and δβ refer to AA 5052 side), α_t represent the theoretical angle and α_{avg} represent the average angle

2.5 Taguchi Method

The Taguchi method is an effective statistical tool for analysing and suggesting optimal parameters [35]. In this study, to determine the most significance among four independent factors, each with three factor level values, the L9 orthogonal array was employed. Table 3 summarizes the experiment setup proposed by the Taguchi method.

In the Taguchi, the terms "signal" and "noise" refer to the desired value (mean) for the output characteristic and the unwanted value, respectively. Taguchi measures the quality characteristic deviating from the desired value using the S/N ratio. There are three types of S/N ratios, and for this study: Smaller is better has been chosen; the following equation calculates the quality characteristic of smaller is better.

Table 3: Taguchi orthogonal array L_9

No of Experiment	Rotational Speed (RPM)	Feed Rate (mm/min)	Step Size (mm)	Wall Angle (°)
1	1250	800	0.2	55
2	1250	900	0.3	60
3	1250	1000	0.4	65
4	1500	800	0.3	65
5	1500	900	0.4	55
6	1500	1000	0.2	60
7	1750	800	0.4	60
8	1750	900	0.2	65
9	1750	1000	0.3	55

$$S/N = -10 \log (\Sigma(Y^2)/n) \quad (3)$$

In the provided factor level combination, Y denotes the number of responses, and n denotes the total number of responses in the factor level combination. The S/N ratio in Taguchi analysis indicates the best values for every parameter and, depending on the ranking, pinpoints the parameter that had the biggest impact on the response. The pattern or relationship between the parameters and the response is displayed by the means value, however.

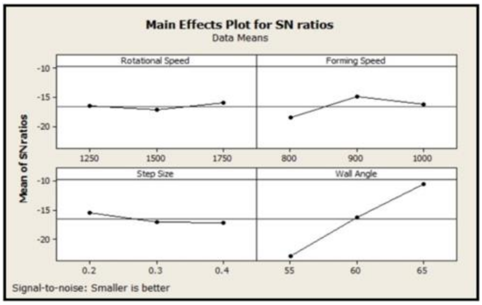
3.0 RESULTS AND DISCUSSION

Table 4 shows the results of the springback obtained from the experiment. Sample no. 8 showed the lowest value of springback on both sides of the material compared to other samples. As can be seen in Figure 7(a), the optimum values are at a rotational speed of 1750 rpm, a feed rate of 900 mm/min, a step size of 0.2 mm, and a wall angle of 65°. While in Figure 7(b), the springback depicts an insignificant impact on both step size and rotational speed. While the high feed rate values also result in low springback values, the value of springback decreases by increasing the value of the wall angle, and the wall angle value of 65° produces less springback compared to 60° and 55°. At a higher wall angle (e.g., 65°), the material undergoes more homogeneous deformation with less localised stress concentration, resulting in less springback because there is less residual stress and strain energy retained in the formed material. Similar findings were made by [36] and [37].

Table 4: Measured springback obtained from experiment

No of samples	Factors				Springback (°)	
	Rotational Speed (RPM)	Feed Rate (mm/min)	Step Size (mm)	Wall Angle (°)	$\delta\alpha$	$\delta\beta$
1	1250	800	0.2	55	15.410	11.943
2	1250	900	0.3	60	5.637	8.547
3	1250	1000	0.4	65	3.455	3.985
4	1500	800	0.3	65	4.734	6.265
5	1500	900	0.4	55	13.329	12.624
6	1500	1000	0.2	60	5.903	8.016
7	1750	800	0.4	60	8.194	8.595
8	1750	900	0.2	65	2.285	2.662
9	1750	1000	0.3	55	13.355	12.461

Figure 7(c) illustrates the ideal testing to find the least amount of spring back angle on the AA 5052 side, in line with earlier analysis on the AA 6061 side. For the least amount of springback, the ideal rotating speed was 1750 rpm, the feed rate was 900 mm/min, the step size was 0.2 mm, and the wall angle was 65°. The springback was inversely proportional to the wall angle, as seen in Figure 7(d). On the other hand, springback on the AA 5052 side was slightly impacted by other parameters including rotating speed, feed rate, and step size. In most cases, the springback on right side, which was on AA5052 material depicted larger value sue to the fact that AA5052 owns higher modulus of elasticity compared to AA6061.



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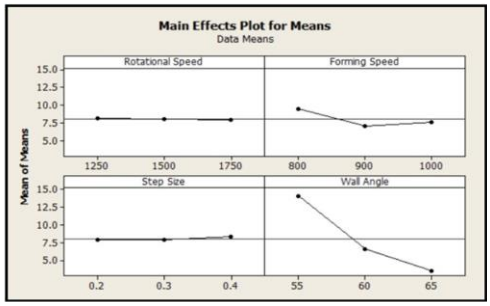

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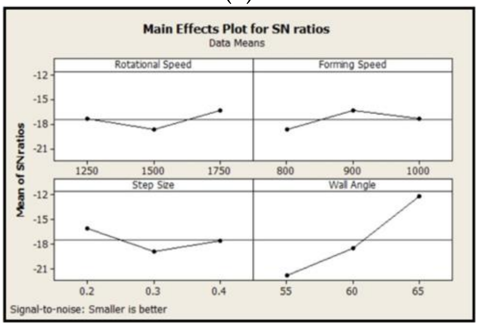

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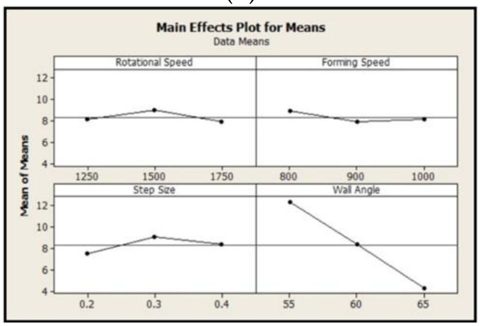

(d)

Figure 7: (a) The S/N ratio for springback, α, (b) mean value for springback, α, (c) The S/N ratio for springback, β and (d) mean value for springback, β

Table 5 presents a summary of all measured springbacks according to the Taguchi method's major parameter ranking level analysis. It was discovered that wall angle had the greatest influence on springback, although rotational speed had less of an impact than feed rate and step size.

Table 5: Level of significant factor

Measured side	Rotational Speed (RPM)	Feed Rate (mm/min)	Step Size (mm)	Wall Angle (°)
Springback α	4	2	3	1
Springback β	4	3	2	1

3.1 Analysis of Variance (ANOVA)

The contribution of each parameter on the springback in the SPIF of dissimilar AA5052 and AA6061 TWBs were then determined using

ANOVA. The summary of ANOVA results for springback is shown in Table 6.

Table 6: The P value (PV) and contribution percentage (C%)

Measured side	Rotational Speed		Feed Rate		Step Size		Wall Angle	
	PV	C (%)	PV	C (%)	PV	C (%)	PV	C (%)
Springback α	0.999	0.05	0.857	5	0.994	0.22	0	94.73
Springback β	0.948	1.73	0.954	1.54	0.899	3.46	0	93.18

In this experiment, as mentioned in the previous sections, springback was measured on two sides of the materials, and the analysis result showed a consensus, where the wall angle was found to be the most significant parameter, while rotational speed was insignificant. The P value for both angles, α and β show the highest contribution percentage at 94.73% and 93.18%, respectively.

3.2 Confirmation Test

The results of the confirmation test are displayed in Table 7. The optimum rotational speed, feed rate, step size, wall angle, and minimum springback values for AA 6061 and AA 5052 sides were 1750 rpm, 900 mm/min, 0.2 mm, and 65°, respectively. These values were the same as those applied to sample no. 8, which yielded a lower value of springback compared to other samples. For AA 5052 and AA 6061, the error percentages were 0.701% and 0.522%, respectively. The error percentage was less than 1%, which was quite low, according to both results.

$$\mathbf{Error} = \left(\frac{\delta_a - \delta_p}{\delta_a}\right) \times \mathbf{100} \tag{4}$$

Where δ_a represent the actual value of springback and δ_p represent the prediction value of springback.

Table 7: Error percentage on confirmation test

		AA 6061			AA 5052		
Parameters	Optimum Value	Springback α (actual)	Springback α (predict)	Error (%)	Springback β (actual)	Springback β (predict)	Error (%)
Rotational Speed (RPM)	1750	2.297	2.285	0.52	2.681	2.6622	0.701
Feed Rate (mm/min)	900						
Step Size (mm)	0.2						
Wall Angle (°)	65						

4.0 CONCLUSION

In conclusion, the objectives of the study were successfully achieved through experiments investigating the influence of SPIF process parameters on springback. The findings reveal that the wall angle has the most significant impact on springback, while rotational speed exhibits the least effect. The optimal process parameters identified for rotational speed, feed rate, step size, and wall angle are 1750 rpm, 900 mm/min, 0.2 mm, and 65°, respectively. The confirmation test further validated these results, showing a low percentage of error 0.522% for AA 6061 and 0.701% for AA 5052 indicating the reliability of the experimental outcomes.

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AUTHOR CONTRIBUTIONS

K.A.H.A. Razak: Conceptualization, Methodology, Software, Writing-

Original Draft Preparation; A.B. Abdullah: Data Curation, Validation, Supervision; M. Mohamed: Software, Validation, Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission and declare no conflict of interest on the manuscript.

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