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Identifying the most significant parameter in stir casting process for optimizing the effect of nano reinforcement MWCNT on AA 7075-T651

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The purpose of this research is to determine the most important factors affecting the mechanical properties of hybrid aluminum metal matrix composites (MMCs). The literature review and the pilot experiments both helped to determine which variables were most and least important. The fishbone diagram visually represented the identified elements, but it ignored the meaning of the responses provided. FMEA, which stands for Failure Mode and Effect Analysis, was used to identify critical parameters from among all of the elements shown in the fishbone diagram. After that, we used a Plackett–Burman layout to narrow down the list of relevant elements and identify the most influential ones. It was found that stirring time, speed, and reinforcement were among the most crucial factors in achieving ultimate tensile strength (UTS) is high, and Hardness.

***Keywords*: Aluminum Metal Matrix; Nano Reinforcement; Fishbone Diagram; FMEA; Screening Design; UTS; Hardness.**

INTRODUCTION

Metal matrix composite

Researchers have been concentrating their efforts, over the course of the past few years, on the manufacture of materials that are both lightweight and strong. The conclusion that should be drawn from the findings of this study is that researchers should concentrate their efforts on composite materials. A composite material is the result of combining at least two distinct materials in order to produce a more stable substance. In general, composite materials are classified into many categories based on the physical or chemical; the grid stage's characteristics, such as metal networks, polymer framework; and burned blends[1,2]. Metal matrix composites (MMCs) that have been reinforced with a variety of nanomaterials, also known as metal matrix nanocomposites (MMNCs), are currently being investigated all over the world as a result of the promising features that make them suitable for an extensive variety of business applications[3,4]. Aluminum, magnesium, and titanium, as well as amalgams of these metals, are the grid's most common constituents. It is usual practice to use backing as a means of enhancing the properties of an inferior metal, such as strength, conductivity, wear resistance, and so forth. As a result of its thinness, lightness, strength, unmatched adaptability, ease of machining, and ease of welding, aluminum has astounding use resistance, and the finest heat and electrical conductivity, among other properties. Also its mixes are of interest in MMCs as a base metal due to these characteristics. The most commonly used components in the production of composites are aluminum mixes. The other component implanted in this metal acts as a fortification for the structure. In most cases, the steps of production involve the employment of mono filaments, hairs, strands, or particle types. Nowadays composite materials containing aluminum has obtained criticalness in aircraft, car, and underpinning applications as a result of their improved mechanical characteristics and outstanding solidity in a hot environment[5]. This is due to the fact that these materials may be used in a variety of applications. Composites made of aluminum and another metal, also known as aluminum metal matrix composites (AMMCs), are made by a variety of various assembling processes, such as mix casting, powder metallurgy, pressure invasion, crush casting, and so on[6]. However, the stir casting technique is the effective approach for generating composite materials, making it preferable over other processes[7]. Among all the cycles, mix projecting is the most common one, followed by synthetic fume affidavit approach, which is the most well-known and frequently cycle used by the professionals. Controlling the structure and the attributes of composites requires having precise command over the

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nanoparticles' dimensions, as well as their classification and storage. It is possible for the mechanical properties of the composites to reduce the size to better of the nanoparticles[8–10]. The new class of AMMC is being considered for several applications in businesses resulting from its superior mechanical properties, convenience of use, and low weight. AMMCs are also capable of being produced using a variety of processes. The distinctive trademark profile was achieved through the utilization of a variety of production strategies over the cycle of manufacturing and the incorporation of a wide range of auxiliary materials. The purpose of this investigation is to examine the production process and many elements that have an influence on the behavior of Nan reinforcement in AMMCs[11]. When introduced as a reinforcement element, multi-wall carbon nanotubes (MWCNTs), which consist of three-dimensional (3D) carbon tubes, provide a considerable boost to the base matrix's strength. It is compact and lightweight. Extremely tiny weight percentages of evenly distributed (vol. % or wt. %) MWCNTs is sufficient to efficiently enhance mechanical characteristics. Due to its limited when combining liquids, wettability, MWCNTs Resilient composites are often manufactured via solid-state processes, such as extrusion or heat pressing, following pre-mixing matrix and nano-sized MWCNTs powders. MWCNTs will agglomerate inside the structure of the matrix regardless that was produced processes, matrices, or chemical treatments used. Because of this, there is an issue with the dispersion of MWCNTs in the matrix materials, which reduces the strength of the composites. Because of their high affinity, MWCNTs lead to the formation of tiny clusters or agglomerates and alter the texture of grain boundaries[12]. AA7075 is the extensively used alloy of the 7xxx series since this has a blend of strength, ductility, and toughness. This alloy possesses very high strength, excellent strength-to-weight ratio, superior toughness, high electrical and thermal conductance, very good resistance to wear and abrasion, damage resilience at higher and cryogenic temperatures, good fatigue strength, resistance to creep, good corrosion resistance, and high elongation during the time of failure. It finds applications in aerospace, aircraft, electronic, military, and automobile components[13].

Stir casting process

The simplest and most widely used method is the "vortex technique," also known as "stir casting," which is appealing due to its simplicity, low processing cost, flexibility, and economic viability in the preparation of large-sized components and the creation of pieces that resemble a net. Its vortex method incorporates the addition of ceramic particles that have been prepared to the center of a created a swirl of molten alloy a revolving impeller. The stir casting rig is depicted in **Fig. 1**.

Stir casting's two-step mixing technique is an intriguing new innovation. The metal is completely melted in this procedure by heating the matrix material above its liquids temperature. In order to maintain a semi-solid state, the temperature of the melt is lowered to a position between that of liquids and solids. The particles are inserted and blended in at this point after being warmed. Again, the slurry is brought to a boil and given a good stir until it is completely liquid. Creating aluminum has traditionally used a two-step mixing process. When compared to other well-established processes of fabricating among MMCs, stir casting is the most common and cost-effective. As a result, stir casting has emerged as the preferred commercial technique for making aluminum-based composites[14].

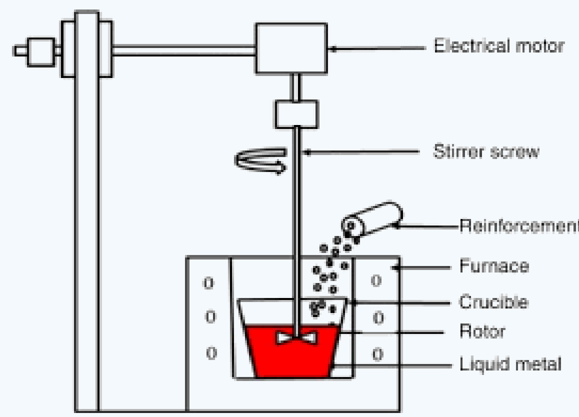

Figure 1 Stir casting process.

Fishbone diagram method for stir casting process parameter

The Ishikawa (or fishbone) diagram was developed to help pinpoint and categorize the root causes of a quality issue. Over time, this approach has also been utilized to classify the root causes of other challenges a company faces. Because of this, the fishbone diagram has developed into a powerful tool for risk detection process[15]. A fishbone diagram can be used to show the chain of causation for a stir casting method's given reaction. Literature evaluation and experimental experience were used to create fishbone diagrams for ultimate tensile strength (UTS) and hardness analysis of the newly created material. A fishbone diagram can give you an indication of how many different process factors are at play when it comes to influencing a particular reaction, but it won't tell you anything about the most important characteristics.

Literature-based considerations that modify AMMC attributes like hardness, UTS, particle distribution, and more. The information used to make the fishbone schematics comes from a variety of studies done on the stir casting procedure. To illustrate the causes of UTS and hardness, **Figs. 2 and 3** are fishbone diagrams. The representation takes into account several factors such as environmental factors, human capacities conditions, the materials for reinforcement, the matrix, machining process, etc.

Failure mode effect analysis (FMEA) for UTS and hardness

FMEA is a methodical approach for analyzing failure mechanisms and the causes and consequences of potential design, production, or assembly flaws. It's a typical instrument for such analysis. The FMEA is used to prioritize the most critical failures and then take steps to eliminate or decrease them. In the business world, FMEA is used to evaluate a process or product before it is released to the public. It tells you what to look out for in terms of process or product failure-causing characteristics[16].

In FMEA Risk Priority Number (RPN), using the formula RPN = O × S × D, the (Risk Priority Number) score was determined.

One was thought to be the lowest score in each area, and 5 was thought to be the greatest.

Based on available literature and experience, 60% threshold depending on RPN score for the factor's selection of the greatest RPN value (i.e. RPN = 125) (i.e. RPN = 75).

The FMEA approach was successful among other things because of its simplicity. For each failure mode only three questions had to be answered: how often does it occur, how severe is the failure, and to what extent can it be detected. FMEA is a structured approach to discover potential failures that may exist within the design of a product or process[17].

Assign severity ratings

The identified effects should be ranked in order of severity. According to this ranking, the potential impact of an event is estimated in terms of its seriousness. The severity of an effect can be gauged by thinking about how it would affect the product or process, as well as how it would affect subsequent processes and the running of the process itself. According to **Table 1**, the severity is ordered on a relative scale from 1 to 5.

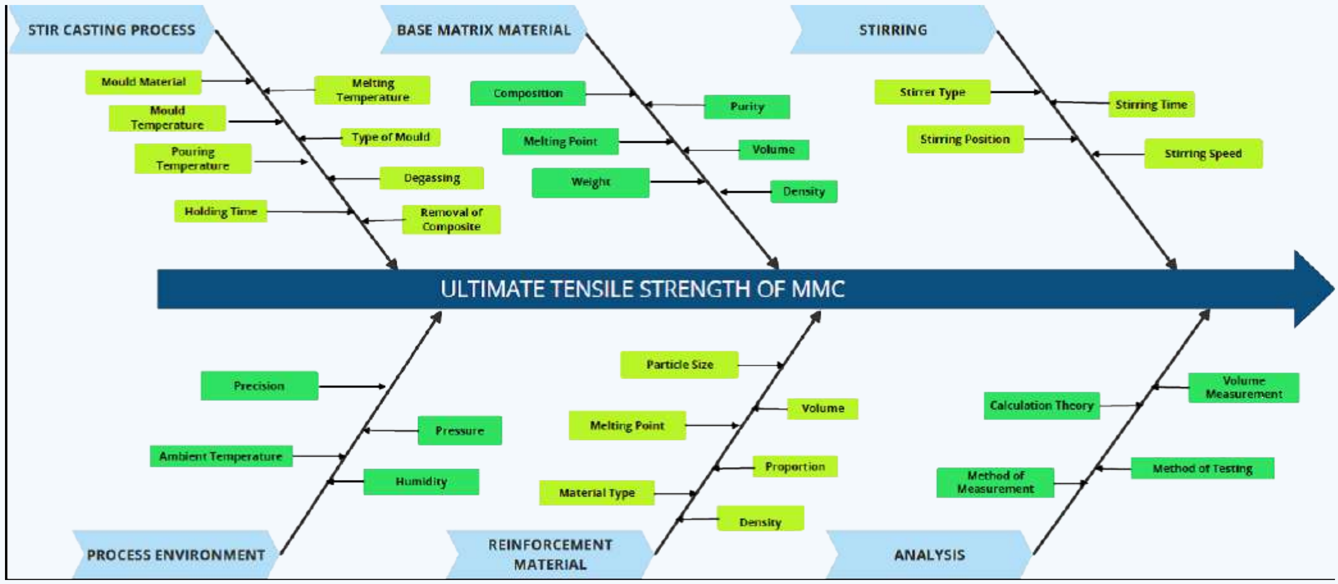

Figure 2 Fishbone diagram for UTS.

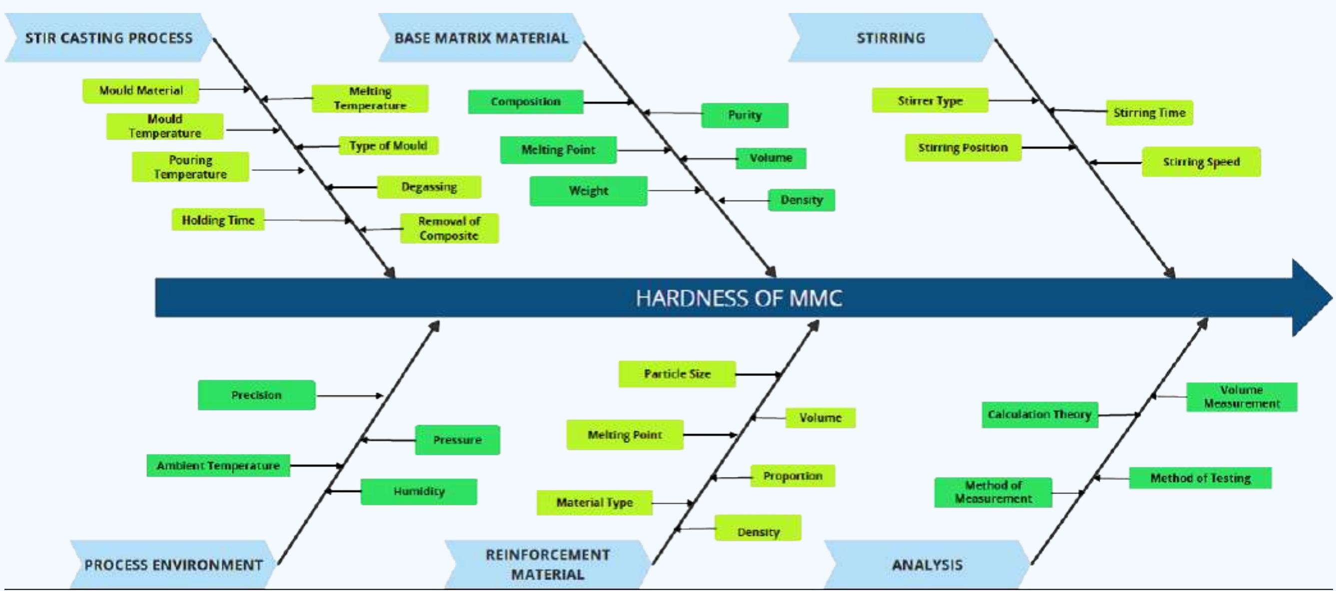

Figure 3 Fishbone diagram for hardness.

Assign occurrence ratings

Calculate the likeliness that the failure will occur. Put each of these reasons or breakdown methods in order of how often they occur. The ranking of the occurrence is based on the probability that the cause (or failure mechanism) will occur. Similarly according to the severity rating scale presented in **Table 2**, the occurrence ranking scale ranges from 1 to 5.

Assign detection rating

Assigning detection rankings entails first identifying the process or product relevant controls in existence for each failure scenario, and then assigning a detection ranking to each control. The detection ranks assess the effectiveness of the present process controls. **Table 3** displays a relative ranking scale for detection, which, like the severity and occurrence scales, ranges from 1 to 5.

Table 1 Severity ratings.

Rank	Effect	Description
1	Very slight	Effect of blade angle in stirring process
2	Moderate	Effect of mold temperature
3	Severe	Effect of Preheating temperature
4	High severity	Effect of percentage of reinforcement
5	Extreme severity	Effect of stirring speed

Table 2 Occurrence rating.

Rank	Occurrence	Description
1	Extremely unlikely	Impact of blow holes on failure
2	Low likelihood	Percentage of occurrence of blow holes
3	Moderately likelihood	Occurrence of shrinkage
4	High likelihood	Effect of shrinkage on failure
5	Extreme likelihood	Percentage of improper solidification during casting

Table 3 Detection rating.

Rank	Detection	Description
1	Extreme likelihood	Failure detected due to brittleness
2	High likelihood	Failure detection due to high density of composites
3	Moderately likelihood	Failure detected due to stirrer geometry and position
4	Low likelihood	Failure detected due to mixture temperature
5	Extremely unlikely	Failure due to expanse

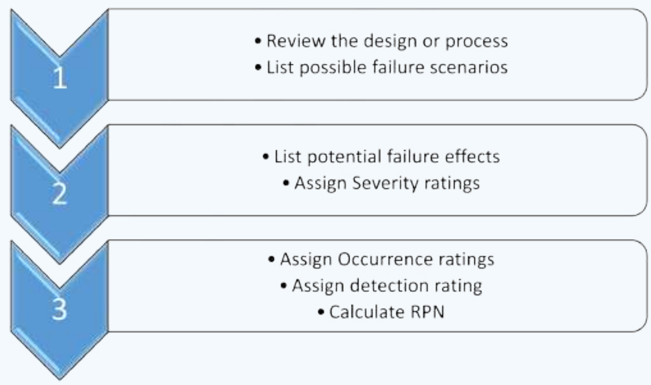

Figure 4 Steps to conduct a FMEA.

One was thought to be the lowest score in each area, and 5 was thought to be the greatest. Based on available literature and experience, 60% threshold regarding the factor's selection, the greatest RPN value (i.e., RPN = 125) is 75 for the RPN score. From abovementioned table data of FMEA, RPN score above 75 is considered a significant parameter to take it to further screening process to find the most significant parameter for experimentation and developing AMMC.

Experimental setup and materials for screening design

The initial stir casting operation was built with a small electric furnace and stirrer. The stirrer has a speed regulator and an electronic speed indicator, while the furnace has an internal temperature sensor and digital temperature display. The duration of the stirring was timed with a stopwatch. For the purpose of gauging the UTS and hardness of the 7075-T6 aluminum, Jirkon Metal and Engineering fashioned a pattern of test bars in accordance with the ASTM E8 criteria, as illustrated in **Fig. 7**. Carbon nanotubes were added to the molten aluminum 7075-T6 after the ingot was melted in a furnace and stirred. The composites were made by mixing molten aluminum with either 5% or 3% by weight of multi-walled carbon nanotubes (MWCNTs). Aluminum with MWCNTs is poured into a mold until it solidifies, **Figs. 9 and 10** illustrate the experimental setup at Sankalchand Patel University workshop.

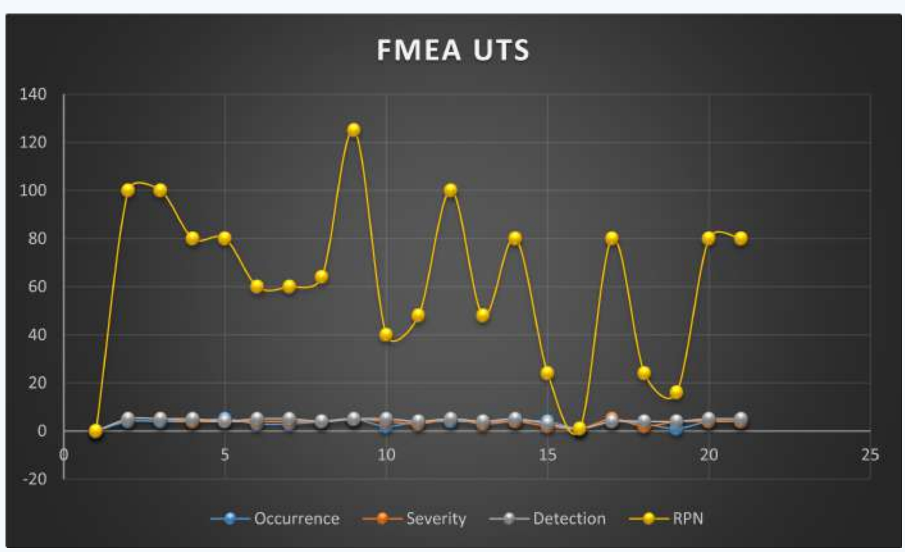

Figure 5 FMEA data representation graph UTS.

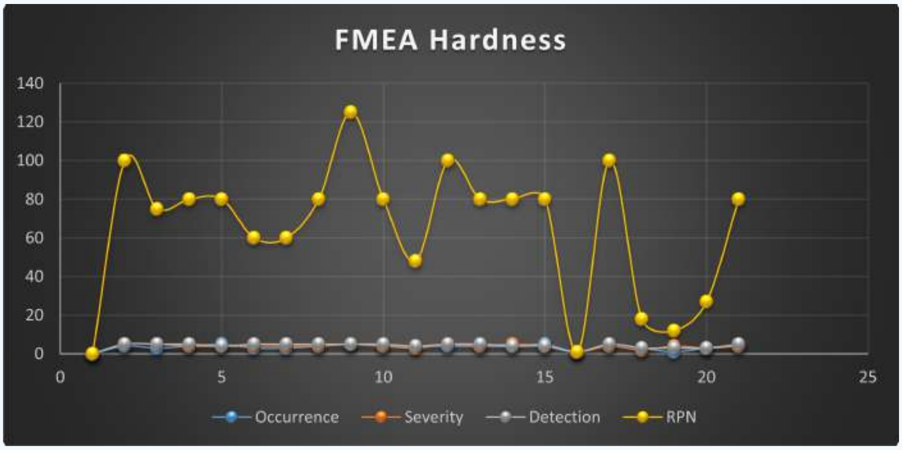

Figure 6 FMEA Data representation graph hardness.

Design of the Plackett–Burman screen

The Plackett–Burman architecture was utilized so that the variables that were derived from the FMEA analysis could be reduced. This screening strategy does not imply that certain parameters have an influence on the response; rather, it gives a list of significant variables that might have an effect on the response. In order to pick the parameters that would go into the screening design, we took into consideration the accessibility of the sources as well as the practicability of stir casting as a technique, utilizing the outcomes of the FMEA to determine the relevant factors.

For the purpose of conducting the analysis, the statistical program Minitab (version 17.1) was utilized as shown in **Fig. 8**. Those that are independent (i.e., those obtained from the FMEA) For the screening design, the following factors are important to consider: the speed of stirring, duration of stirring, stirring location, keeping time, reaction time, particle reinforcement size, reinforcement percentages, molten metal flow temperature, and die temperature. The responses for this design are hardness and UTS. In addition, the thresholds for each element were chosen after considering the amount of relevant literature. Composites were made by applying the levels stated in **Table 6** to the ingredients. While the amount of other reinforcements was kept the same throughout the manufacturing stage, the amount of MWCNT was changed from 0.5 to 3 weight percent. The procedures that were used in the production of the composite are outlined in **Table 6**.

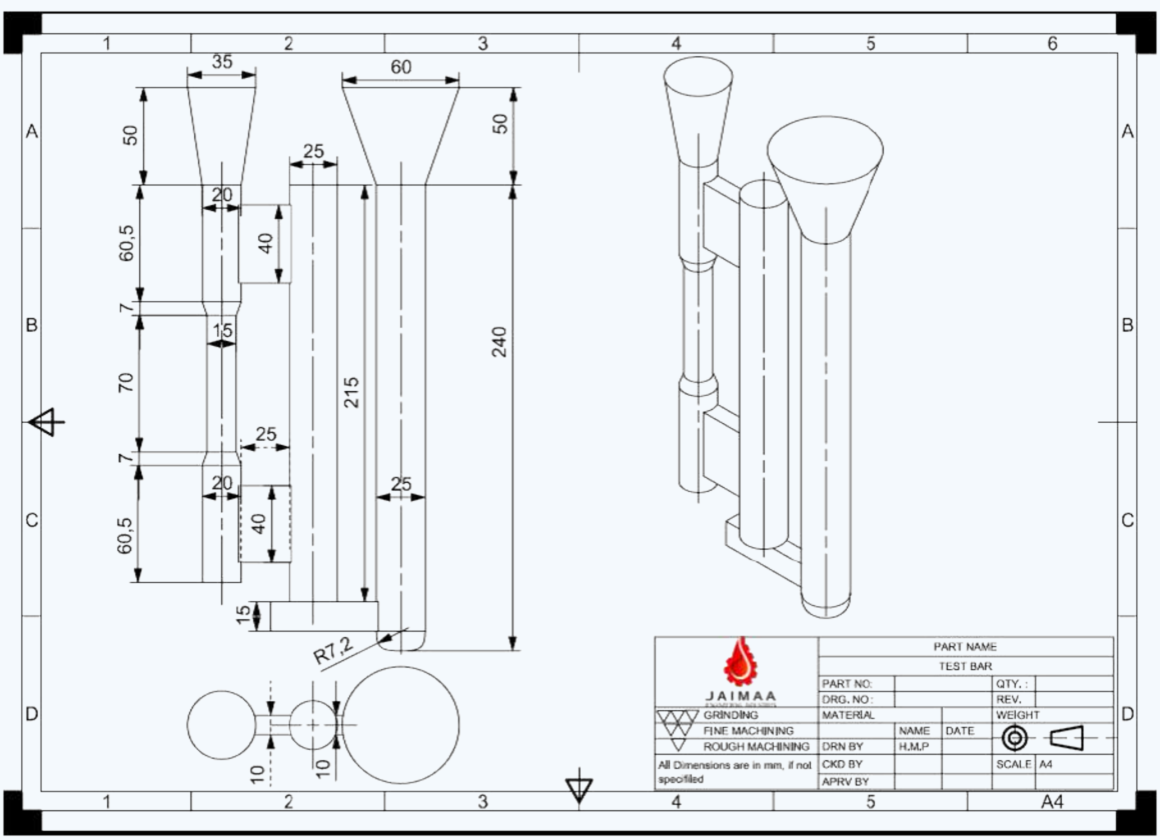

Figure 7 Test bar patten as per ASTM E8.

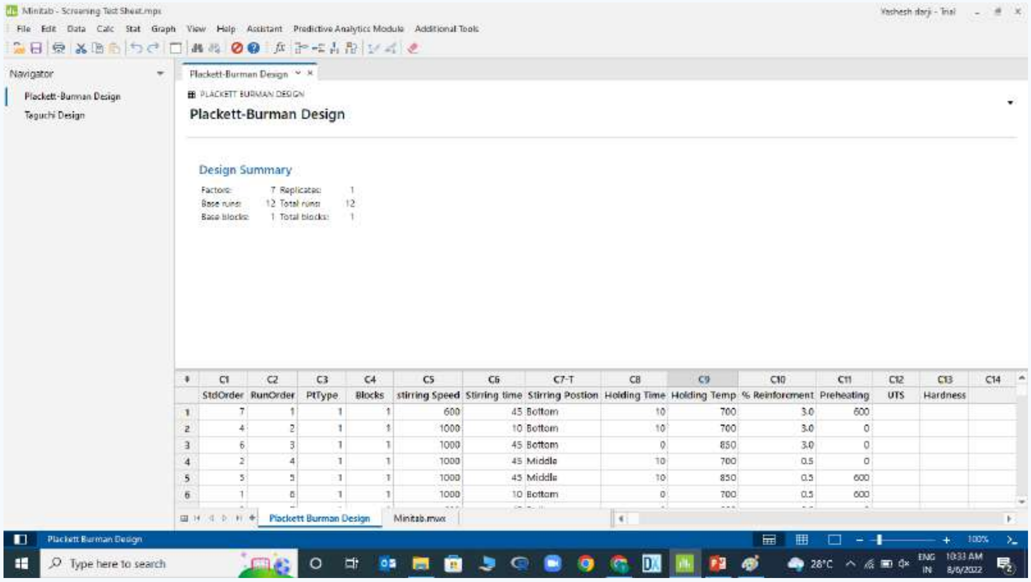

Figure 8 Plackett–Burman design run for experimentation.

Figure 9 Preparing the mold and setup.

Enhancement of the screening design

To improve curcumin's solubility and bioavailability, researchers examined the effects of formulating the compound with other excipients in the form of solid lipid nanoparticles. Researchers used a screening methodology to determine which parameters had the most impact on the fabrication process and which parameters had the greatest combined impact. They arrived to the conclusion that the screening design has the problem of not displaying the interaction impact. Therefore, it is challenging to determine the set of circumstances causing the shift in reaction. Furthermore, it does not indicate the parameters' levels[18]. Therefore, following screening, optimization of parameters is essential. In order to achieve both a high UTS and hardness, the screening parameters were optimized using a factorial design. The optimization method was simplified and made more cost-effective by not changing the preheating temperature or the

Figure 10 Experiment and preparing the AMMC.

Table 4 For FMEA UTS data.

	UTS			
	Failure mode and effect evaluation			
Components	O”	S”	D”	RPN
Reinforcement type	4	5	5	100
Reinforcement percentages	4	5	5	100
Particle reinforcement size	4	4	5	80
Furness foreheat	5	4	4	80
Molten metal flow temp.	3	4	5	60
Pouring distance	3	4	5	60
Temp. molten material	4	4	4	64
Speed of stirrer	5	5	5	125
Stirrer orientation	2	4	5	40
Stirrer diameter	4	3	4	48
Stirring duration	4	5	5	100
Die temp.	4	3	4	48
Keeping time	4	4	5	80
Reaction time	4	2	3	24
Blending	1	1	1	1
Constraint	4	5	4	80
Material moisture levels	3	2	4	24
Material reactivity in the matrix	1	4	4	16
Mold greasing	4	4	5	80
Holding temp.	4	4	5	80

Table 5 FMEA data for hardness.

	Hardness			
	Failure mode and effect evaluation			
Components	O”	S”	D”	RPN
Reinforcement type	4	5	5	100
Reinforcement percentage	3	5	5	75
Particle reinforcement size	4	4	5	80
Furness foreheat	5	4	4	80
Molten metal flow temp.	3	4	5	60
Pouring distance	3	4	5	60
Temp. molten material	4	4	5	80
Speed of stirrer	5	5	5	125
Stirrer orientation	4	4	5	80
Stirrer diameter	4	3	4	48
Stirring duration	4	5	5	100
Die temp.	4	4	5	80
Keeping time	4	5	4	80
Reaction time	5	4	4	80
Blending	1	1	1	1
Constraint	5	4	5	100
Material moisture levels	3	2	3	18
Material reactivity in the matrix	1	4	3	12
Mold greasing	3	3	3	27
Holding temp.	4	4	5	80

Table 6 The process taken up for the rehocast of the combined AA 7075-T6 in designing the screening.

1	Percentage wt. of MWCNT conversion in to weight
2	Scaling up the reinforcement weight
3	Additions are heated to a temperature of 600°C in the furnace
4	Aluminum 7075-T6 metal melting
5	Mixing while incorporating reinforcing 10 to 45 minutes at an RPM of 200 to 1,000
6	After adding reinforcement, keep the blend still
7	Pouring and solidification
8	Quenching in hot water to about 60–80°C
9	Testing the hardness and UTS

percentage of reinforcement[19]. Time and agitation rate are two obvious examples of independent variables, whereas hardness and UTS are two examples of dependent variables. Both the agitation rate (600–1,000 rpm) and the stirring time (10–45 minutes) were maintained at constant levels. The proportion of reinforcement was held constant throughout the trials so that the effects of stirring speed and stirring time could be determined.

RESULTS AND DISCUSSION

After reviewing the available literature and doing some preliminary experiments with composites, we identified several parameters that contribute to the material's unique behavior. So, fishbone diagrams were drawn up to show every single variable, no matter how little it was. FMEA analysis combined with a cause-and-effect (fishbone) diagram successfully identified bottlenecks throughout the ready-to-eat-fruit sector. As a result, the fishbone diagram was used as a basis for the FMEA analysis used in the present investigation. For the cast composite's UTS and hardness[20], the important metrics were provided by FMEA. It

Table 7 Plackett–Burman design experiments runs.

Run order	Speed of stirring	Stirring duration	Stirring orientation	Keeping time	Keeping temp	Percentage reinforcement	Preheating	UTS	Hardness
1	600	45	Bottom	10	700	3	600	**892.32**	**84.53**
2	1,000	10	Bottom	10	700	3	0	**880.88**	**82.39**
3	1,000	45	Bottom	0	850	3	0	**869.44**	**80.143**
4	1,000	45	Middle	10	700	0.5	0	**663.52**	**64.842**
5	1,000	45	Middle	10	850	0.5	600	**657.8**	**64.307**
6	1,000	10	Bottom	0	700	0.5	600	**674.96**	**66.34**
7	600	45	Bottom	0	850	0.5	0	**680.68**	**67.945**
8	1,000	10	Middle	0	850	3	600	**886.6**	**81.855**
9	600	10	Middle	10	850	3	0	**909.48**	**86.67**
10	600	45	Middle	0	700	3	600	**880.88**	**84.53**
11	600	10	Bottom	10	850	0.5	600	**697.84**	**69.015**
12	600	10	Middle	0	700	0.5	0	**697.84**	**68.48**

Figure 11 Preparing the specimen as per ASTM E8 for UTS and hardness test.

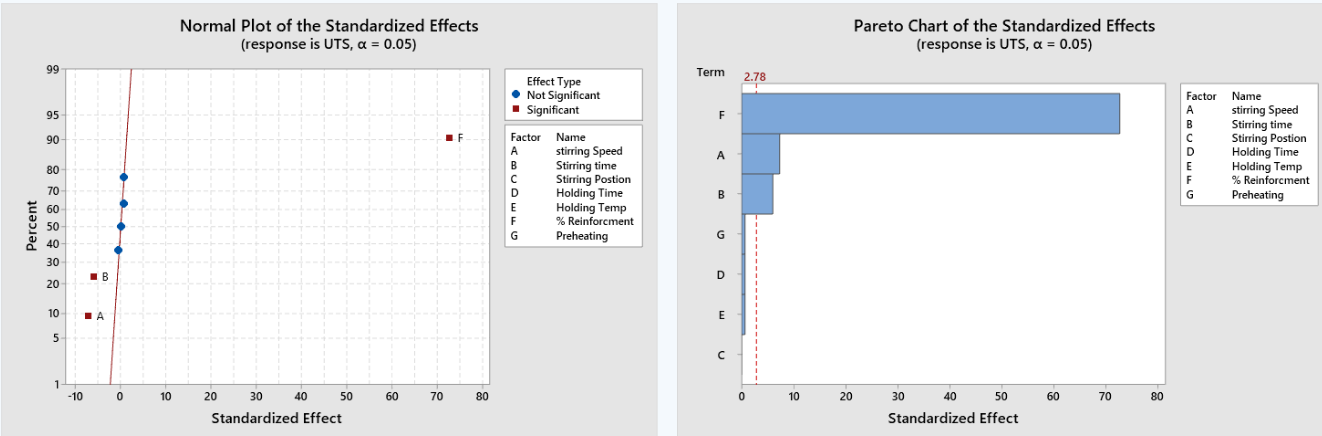

Figure 12 For the Plackett–Burman design, Pareto, and standard effects charts.

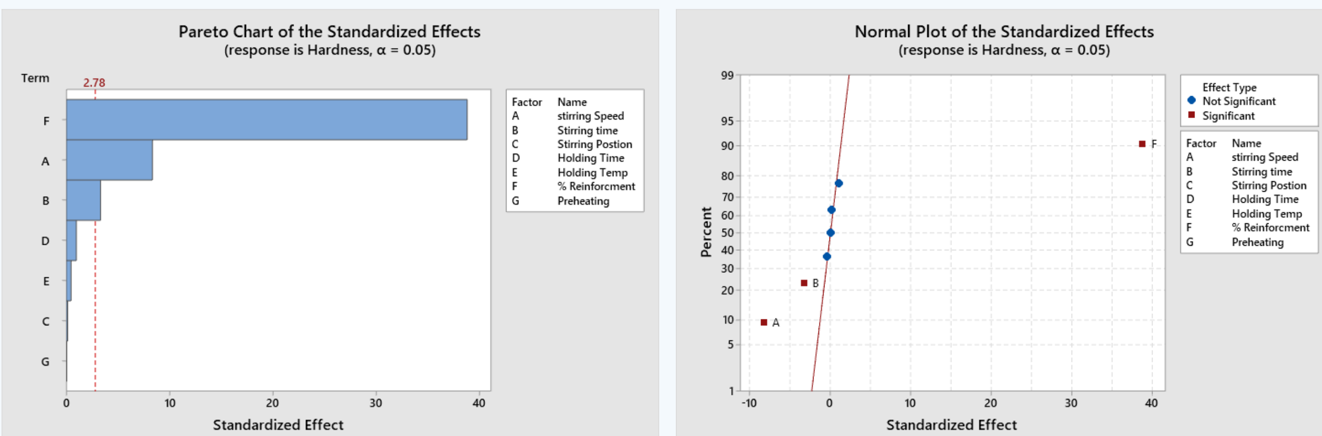

Figure 13 Pareto and normal effect graphs for hardness for Plackett–Burman design.

can be seen from **Table 4** and **Fig. 5** that the most important variables for UTS are the kind, the amount of reinforcement, and the dimension of the reinforcement's particles, whether or not the reinforcement is preheated, the stirring speed, the stirring duration, the holding time, the pressure, and the stable temperatures. Correspondingly, **Fig. 6** and **Table 5** show the significant factors for hardness, including the sort of bolstering, the percentage of reinforcement, its dimension, how hot it is when it is heated up, how hot the fluid melt is, the stirring speed, the stirring position, the moving time, the fungus temperature, the holding time, the mixing time, the pressure, and both the storage temperature and the surrounding environment.

The study's parameters were further ranked by using Plackett–Burman design. From the relevant parameter obtained by FMEA, it was used to identify the most important parameters. Constants include things like atmospheric pressure and temperature. The results of the screening experiments, as well as the UTS and hardness values, are shown in **Table 7**. **Table 7** and its accompanying graph display the results of all of the tests conducted on UTS and hardness. **Figure 12** displays both the standard impact and balanced charts for the UTS, and the results show that pace, duration, and reinforcement of the stirring percentage are the most important parameters for the UTS, while **Fig. 13** displays both the standard impact and balanced charts for hardness, and the results show that these same three variables are also the most important for the hardness.

In order to measure the UTS and hardness of the cast aluminum 7075-T6 reinforced with MWCNT shown in **Fig. 11**, the specimen was machined on a lathe machine in accordance with the ASTM E8 standard.

CONCLUSION

The elements that influence responses were graphically represented using fishbone diagrams. Using FMEA analysis, the significant factors for UTS were determined to be the kind of reinforcement, reinforcement percentage, particle reinforcement size, heating of reinforcement, stirring speed, stirring time, holding time, pressure, and thermodynamic stability. Accordingly, important variables for pores include the category of reinforcement, reinforcement percentage, particle reinforcement size, heating of strengthening, temperature of the fluid's melt, stirring speed, position, and time, as well as the temperature of the mold, degassing, holding time, and mixing time.

In addition, a screening process was utilized in order to determine which of the relevant parameters' list of characteristics were the most significant. For UTS and hardness, the percentage reinforcement, stirring speed, stirring time, and preheating temperature were observed to be significant factors. On the other hand, for UTS and hardness, the percentage reinforcement, preheating temperature, stirring speed, and stirring time were considered to be significant parameters.

The findings of the research on optimization led to the conclusion that the ideal range of stirring speed and time for a particular composite was between 600 and 1,000 rpm and between 10 and 45 minutes, respectively. This conclusion was reached as a result of the findings of the optimization research. Because of an optimized range of stirring speeds, stirring duration, preheating of reinforcement, and heat treatment, the UTS increased up to 234.52 MPa. And the hardness improved up to 20.22 HRC as a result of improved stirring time and reinforcing. Hence, based on the Plackett–Burman Design, the most significant parameter was identified for further factorial experiment design.

CONFLICTS OF INTEREST

The authors have no conflict of interest to declare

FUTURE SCOPE

After conducting the screening design, the most relevant parameter is selected, and DOE will be utilized to optimize that process parameter for improved mechanical and microstructure characteristics of AA 7075-T6 composite material.

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