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Exploring Manufacturer Perspectives: The Market Viability and Applications of Multifiber Reinforced Acrylonitrile Butadiene Styrene (ABS) Composite in India's Advanced Engineering, Tooling, And Electric Vehicle Industry with Additive Manufacturing

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Abstract
Exploring manufacturer perspectives: the market viability and applications of multifiber reinforced acrylonitrile butadiene styrene (ABS) Composite in India’s Advanced Engineering, Tooling, and Electric Vehicle Industry with Additive Manufacturing" examines the adequacy and use of multifiber reinforced acrylonitrile butadiene styrene (ABS) composite in the electric vehicle (EV) advanced engineering, and tooling industries in India. Investigating electric vehicle (EV) sales and composite material uses in India's car sector, the study draws on primary and secondary sources of information. Important demographic and research characteristics were illuminated by primary data collected by a structured questionnaire using a stratified random sampling procedure. In all, 185 different firms took part in the poll. Supplemental data was gathered from a wide range of reputable sources to bolster the study. These sources included websites, newspapers, journals, and various online media platforms. Applying statistical methods such as regression, correlation, standard deviation, and mean, the data was analyzed using Excel and SPSS software. The study methodology was cross-sectional. Using these statistical methods, the study attempted to test hypotheses about manufacturers' technical preparedness, the role of technological limitations and workforce training in the difficulties of using acrylonitrile butadiene styrene (ABS) composite, and the difference in product quality and performance between using acrylonitrile butadiene styrene (ABS) composite and using traditional materials. This study provides crucial insights for manufacturers, policymakers, and stakeholders in the advanced engineering, tooling, and electric vehicle (EV) industries in India by analyzing the potential market viability and applications of multifiber-reinforced acrylonitrile butadiene styrene (ABS) composite. The methodology used in the study is thorough and analytical.

Keywords: Manufacturer Perspectives, Market Viability, Advanced Engineering, Electric Vehicle, Additive Manufacturing, Acrylonitrile butadiene styrene (ABS)

1. Introduction

Rails, planes, rockets, and satellites are just a few examples of the many structural products that have made extensive use of fiber-reinforced elastic polymer matrix composites and fiber-reinforced plastic polymer matrix composites. A high level of reliability in the composite strength is necessary for widespread use to avoid catastrophic accidents. Researching composites' strength and fracture mode is, hence, crucial. In most cases, multiple phases make up a composite. Composites' strength and fracture toughness are affected by their components, interface, and the dispersion of flaws. Composite mechanical property prediction based on composition is a basic problem. Neither a model nor a fracture criterion for mechanical analysis has been universally accepted. Conventional finite element models treat composites as if they were anisotropic (Li et al., 2006). The models cannot capture the impact of interfacial debonding—where the bond between the fiber and the matrix fails—on composite mechanical characteristics.

Shear-lag models are a common analytical approach used in meso-mechanical analysis to predict the stress transfer between fibers and the surrounding matrix in a composite material. While these models can be utilized to determine the concentration of stress due to fiber fracturing, they traditionally fail to account for the stress exerted on the matrix, which is critical for understanding the overall mechanical behavior of the composite. Microdamage refers to the accumulation of small-scale damage within the composite, such as fiber breakage, matrix cracking, and interfacial debonding, that progressively weakens the material and can eventually lead to failure.

The tensile strengths of composites are known to be greatly affected by the mechanical characteristics of the matrix and the qualities of the bonds between its constituent parts. When composites are subjected to external loads, microdamage can occur in a random accumulative fashion, causing fiber breakage, matrix cracking, and interfacial debonding, among other problems.

There is a cascade of microscopic processes that contribute to the stress state of fiber-reinforced polymer-matrix composites failing, such as fiber breaking, matrix cracking, and interfacial debonding (Sonia and Kumari, 2021). Very complicated stress and displacement fields can result from interactions between these fractures alone. It is widely acknowledged that the matrix-fiber interaction is a key factor in regulating the micromechanical failure processes and, by extension, the macroscopic mechanical properties, including strength and durability, of fiber-reinforced composites. It is the weakest fiber that breaks first. Afterward, other fibers and maybe even the matrix take up the slack left by the severed fiber. A crack from spreading into the matrix can be stopped by matrix yielding, interfacial debonding, or interfacial sliding around the fiber breakpoint. When the initial fiber breakpoint happens, the constitutive reaction of the fibers, matrix, and interface decides how the load from the broken fiber is transferred among the remaining undamaged fibers and the matrix. Depending on the distribution of fiber strengths, stress redistribution can lead to stress concentration, which in turn puts more strain on the matrix and the fibers that are still intact. The composite will fail catastrophically when this failure process reaches a critical condition (Li et al., 2008).

1.1 Manufacturer Perspectives on Multi Fiber Reinforced ABS Composite in Advanced Engineering

Due to its adaptability and reduced processing time, Fused Deposition Modelling (FDM) is one additive manufacturing method that has tremendous uses in the industrial sector. Its capacity to create complex composite structures with great design freedom and durability without producing waste sets it apart from traditional production processes like machining and casting. It shortens the product development cycle, which makes mass production easier. Molds, prototypes, and patterns can all benefit from FDM 3D printing's ability to produce objects of varying sizes and shapes. Among the many emerging trends in manufacturing today is additive manufacturing, including 3D printing utilizing FDM. The process of 3D printing involves adding material in layers, allowing for adjustments in process settings such as infill pattern, layer thickness, air gap, raster angle, build orientation, road width, and the number of contours (Radadiya, 2023).

Nevertheless, there are several advantages to using reinforced composite materials in 3D printing, as these materials enhance mechanical qualities in 3D constructions, including tensile strength, hardness, bending strength, impact strength, and so on. The use of ABS (Acrylonitrile-Butadiene-Styrene) as a matrix material, particularly when reinforced with carbon and glass fibers, provides a significant improvement in these mechanical properties. This study proposes the use of carbon and glass fibers as reinforcements in an ABS matrix to form a composite material with enhanced characteristics.

The proposed composite material in this study makes use of carbon and glass fibers as reinforcements and ABS as a matrix material. ABS, known for its mechanical properties and good molding performance, is widely used, though it may not be as resilient at low temperatures compared to other polymers. In contrast, carbon and glass fibers offer superior qualities, such as low density, high strength, excellent dimensional stability, heat resistance, and conductivity. These enhancements make ABS reinforced with carbon and glass fibers an attractive option in the additive manufacturing sector, particularly for producing durable, high-performance components.

Globally, the significance of ABS composites reinforced with carbon and glass fibers lies in their potential to meet the rising demand for lightweight, strong, and heat-resistant materials across various industries. Their applications range from aerospace to automotive sectors, where reducing weight without compromising strength is critical. The adoption of such composites could lead to significant advancements in manufacturing technologies and contribute to more sustainable and efficient production processes worldwide.

1.2 Manufacturer Perspectives on Electric Vehicle Industry

The "energy transition" is underway as nations strive to electrify heat and transportation on a large scale and decarbonize power generation to fulfill climate change objectives. The electricity grid is already facing considerable issues due to the large increases in intermittent and variable production throughout this transition. These challenges are only going to become worse as demand for electric heating and EVs continues to rise. Since the new millennium, the electric vehicle (EV) industry has expanded swiftly, with manufacturers focusing on pure EVs in the last five to ten years. Initially, this growth was driven by hybrid vehicles. More than three million electric vehicles have entered circulation, a growth of more than 50% from 2016. As the industry continues to develop, Bloomberg New Energy Finance predicts that 120 all-electric models will be available by 2020. Several writers have raised the prospect of an upcoming 'tipping point' for electric vehicles when longer ranges and cheaper batteries would make them affordable for the masses. Concerns over air quality and decarbonization are also fueling growing political backing worldwide (Earl and Fell, 2019).

Norway, France, Germany, and India have all declared plans to phase out the sale of gasoline and diesel vehicles by the year 2040, while the governments of China and the Netherlands have shown signs of wanting to follow suit soon. The UK government first proposed this prohibition in 2017. However, there may be immediate issues with the power infrastructure as a result of this increase in EV capacity. Data from studies conducted in the UK indicates that even small groups of vehicles charging at the same time might cause network difficulties.

With both supply and demand becoming more unpredictable and fluctuating throughout the day, the challenges for network management are further intensified by the simultaneous growth in intermittent, renewable production. For this reason, future power systems will have to evolve from those that rely on large-scale, centralized, non-intermittent generation—a model in which supply-side flexibility is provided while demand-side flexibility is relatively passive—to ones in which a variety of sources provides demand-side flexibility and is substantially more dynamic. It will be necessary for the energy system to make use of demand-side flexibility, which encompasses a broad variety of demand-side actions, to lower or move power consumption during peak hours. The terms demand-side response and demand-side management are sometimes used interchangeably; the former often denotes reactions to signals in the market price of electricity, while the latter typically denotes broader efforts to decrease or adjust demand for power during peak hours (Rajaeifar et al., 2022).

Since 2010, the worldwide market for electric vehicles has been seeing consistent growth. The following is a list of the top 15 automotive manufacturing organizations by total electric car sales: annual sales worldwide from 2010 to 2015. The combined sales of electric vehicles by both companies exceed 20,000, with the Renault-Nissan alliance boasting the greatest overall sales at over 250,000 worldwide. With 1.2 million electric car sales through 2015, the United States accounts for around 33%, Europe for 31%, China for 22%, and Japan for 10%. As can be seen, yearly sales of electric vehicles topped the 200,000 marks in 2013, the 300,000 marks in 2014, and the half-million mark in

2015. Around 93% of all electric car sales during that period were accounted for by just 15 businesses. To appeal to a wider range of customers, electric car makers are always working to enhance their products' performance. Markets that provide customer incentives to offset the increased costs of technology and other supporting factors account for the majority of electric car sales worldwide. Major automakers have begun developing their next-generation technologies and have released their first electric car models to the public by 2016 (Slowik et al., 2016).

1.3 Manufacturer Perspectives on Market Viability

As a result of new technology and business strategies, the manufacturing sector is undergoing a time of transformation. The distribution of industrial activity is expected to undergo significant rearrangement. Businesses can expect manufacturing in the future to shift away from massive, faraway plants and toward smaller, more networked production facilities that can respond quickly to market demands. There are new possibilities for policymakers to restore or develop manufacturing capacity, which might make the economy more resilient, lessen trade imbalances, and keep manufacturing jobs and skills. A more redistributed manufacturing (RDM) environment is being ushered in by several factors, such as the need to improve sustainability, the reduction of regulatory risks and cost volatility, the democratization of design, market, and consumer proximity, and the uncertainty surrounding energy and transportation costs (Zaki et al., 2019).

Also, many other types of businesses are starting to see mass customization as a potential business strategy. Manufacturing systems that can adapt to different needs and accommodate small orders are essential for this. Sensors, cloud computing, autonomous robots, additive manufacturing, the IoT, agent-based systems, big data, and the Internet of Things (IoT) are also seeing fast technical breakthroughs. As structures, processes, and products get more specialized and distributed, these technologies are viewed as tools that facilitate redistribution.

Through opening up possibilities at every level of the manufacturing value chain—from design and sourcing through production, distribution, point of sale, and consumer use—the digital revolution is fostering disruptions in the old economic landscapes. In low-volume, high-variety settings, traditional production methods are supplemented by the fast-developing digital manufacturing process known as additive manufacturing (AM). Still, there are a lot of obstacles linked to the whole spectrum of related technologies, which is limiting the implementation of AM in current supply networks:

(i) higher price tag to reach economies of scale with uniform part shapes,

(ii) constrained choice of components, and

(iii) complex social rules that protect innovators from infringement and the legal environment (Tziantopoulos et al., 2019).

The purpose of this study is to examine the potential industrial applications and market viability of sandwiched composites reinforced with dual extrusion printed carbon fiber (CF), glass fiber (GF), and ABS in the electric vehicle (EV), tooling, and advanced engineering industries in India. The study aims to inform industry stakeholders, policymakers, and researchers about the opportunities and challenges associated with adopting this innovative material.

1.4 Objectives and Scope of the Study

The study is divided into eight sections. Section 1 provides an introduction to the subject. Section 2 reviews previous studies by various authors. Section 3 illustrates the objectives of the study. Section 4 describes the research methodologies utilized for the investigation. Section 5 presents the results. Section 6 discusses the findings. Section 7 comprises the conclusions, and Section 8 demonstrates implications, limitations, and recommendations for future research. Finally, references are presented.

2. Literature review

In light of the changing perspectives of manufacturers, several studies have explored the evolving role of fiber-reinforced polymer (FRP) composites and additive manufacturing in various industries. This review is organized thematically to enhance readability and coherence, focusing on mechanical properties, technological challenges, and applications in the automotive and aerospace sectors.

2.1 Mechanical Properties of Fiber-Reinforced Composites

Lightweight components with high tensile strength and stiffness are commonly utilized in the military, automotive, aerospace, and sports sectors, owing to the use of FRP composites. Pervaiz et al. (2021) highlighted that FRP composites, made using additive manufacturing and 3D printing, are essential in these sectors due to their superior mechanical properties. However, challenges remain in improving the mechanical qualities and overcoming the development restrictions of FRP composites. The focus of past studies has primarily been on carbon fiber and polymeric matrices, with significant research into the relationships between different 3D printing techniques.

Recent developments in materials science have expanded the applications of FRP composites. For instance, Chauhan et al. (2022) emphasized that natural fiber-reinforced polymer (NFRP) composites have gained popularity in the transportation industry due to their affordability, minimal environmental impact, and metal-like characteristics. Despite these advantages, gaps remain in understanding the long-term durability and environmental sustainability of these composites, particularly under varying operational conditions.

2.2 Technological Challenges in Additive Manufacturing

Additive manufacturing technologies, particularly in the context of 3D printing, have seen significant advancements, yet they face ongoing challenges. Yi et al. (2019) discussed the German commercial vehicle sector's research into additive manufacturing technologies, focusing on overcoming obstacles, estimating costs, creating hybrid processes, and controlling quality. Wen et al. (2022) further explored the correlation between factory digitization and corporate innovation, demonstrating that financially stable businesses were more capable of embracing digital transformation, thus increasing incentives for innovation. However, a gap exists in understanding how smaller enterprises, especially in developing markets, can adopt these technologies without substantial financial backing.

Niaki et al. (2019) examined the environmental sustainability of additive manufacturing, finding that its impact was less significant than initially believed. Economic considerations and the capacity to create intricate patterns were the primary drivers of adoption across industries. This finding suggests a need for further research into how additive manufacturing can be optimized to reduce environmental footprints, especially in large-scale production environments.

2.3 Applications in Automotive and Aerospace Sectors

The automotive and aerospace sectors have been at the forefront of adopting advanced composites and additive manufacturing technologies. Berkeley et al. (2017) noted that Europe’s adoption of battery electric vehicles (BEVs) was driven by concerns over energy security and environmental impact. However, the transition to BEVs faced several obstacles, such as infrastructure challenges and market readiness, highlighting the need for comprehensive solutions from policymakers.

In the aerospace sector, the use of natural fiber-reinforced composites (NFRCs) has been increasing due to their mechanical characteristics, affordability, biodegradability, and environmental friendliness, as reviewed by Lotfi et al. (2021). The review provided a comprehensive overview of significant technologies, covering production problems, machinability, and monitoring of machining processes. However, there remains a lack of data on the long-term performance of these materials under extreme conditions, which is critical for their adoption in high-stress applications such as aerospace components.

2.4 Advances in ABS Composites

ABS composites, particularly those reinforced with carbon and glass fibers, have gained attention for their potential applications in various industries. Mishra et al. (2023) focused on the role of Fused Deposition Modelling (FDM) in Industry 4.0, highlighting its importance despite limitations in mechanical strength and longevity. This research examined structures, additives, faults, and methods to enhance thermoplastic composites, particularly ABS composites.

Recent studies have further explored the applications of ABS composites in the automotive and aerospace sectors, emphasizing their potential for lightweight, high-strength components. For example, Wang et al. (2020) presented a model for recycling lithium-ion batteries in the electric vehicle market, indirectly supporting the use of ABS composites in battery housings due to their durability and resistance to various environmental conditions. However, there remains a gap in understanding how ABS composites can be optimized for mass production while maintaining their mechanical properties.

2.5 Global Industry Trends and Future Directions

Comparing these findings with global industry trends reveals a strong alignment between the increasing adoption of advanced composites and the shift towards more sustainable manufacturing practices. Nunes et al. (2020) discussed the broadening applications of membrane technology, noting the importance of sustainable materials in today's world. This aligns with the global trend of incorporating environmentally friendly materials and processes in manufacturing, particularly in the automotive and aerospace industries.

Moreover, Eyers and Potter (2017) explored the implementation of additive manufacturing systems (AMS) in commercial production settings, identifying opportunities for strategic growth. They emphasized the need for a more integrated approach to AMS adoption, which is crucial for staying competitive in the global market. This review highlights the growing importance of integrating advanced composites, such as ABS reinforced with carbon and glass fibers, into these evolving manufacturing systems.

2.6 Gaps in Knowledge and Study Objectives

Despite the significant advancements in the field, gaps remain in the current knowledge, particularly concerning the optimization of composite materials for specific industrial applications. The present study aims to address these gaps by investigating the potential of sandwiched composites reinforced with dual extrusion printed carbon fiber (CF), glass fiber (GF), and ABS in the automotive, aerospace, and tooling sectors. By gathering insights from manufacturers and analyzing both primary and secondary data, this study seeks to provide a comprehensive understanding of the opportunities and challenges associated with adopting these innovative materials.

3. Objectives of the study

i Evaluate the technological readiness of manufacturers to incorporate Additively Manufactured Multi-fibre Reinforced ABS Composite into their production processes.

ii Assess the challenges and barriers faced by manufacturers in adopting the composite material, including technological constraints and workforce training.

iii Evaluate the impact of the composite material on the performance and quality of products, including any observed improvements or challenges.

4. Methodology and Data

The study titled "Exploring Manufacturer Perspectives: The Market Viability and Applications of Multifiber Reinforced ABS Composite in India’s Advanced Engineering, Tooling, and Electric

Vehicle Industry with Additive Manufacturing" employed a combination of primary and secondary data collection approaches to achieve its objectives.

4.1 Questionnaire Development

A structured questionnaire was developed to collect primary data from manufacturers in India's automotive and advanced engineering sectors. The development of the questionnaire was informed by specific demographic considerations and research variables that are crucial to understanding the market viability of multifiber reinforced ABS composites. The demographic considerations included the size of the manufacturing firm, its primary sector of operation (e.g., automotive, aerospace, tooling), and its level of engagement with additive manufacturing technologies. The research variables focused on factors such as the current use of composite materials, perceived challenges in adopting new materials, and the anticipated benefits of using multifiber reinforced ABS composites.

The questionnaire was designed to capture both qualitative and quantitative data. It included a mix of open-ended questions, Likert scale items, and multiple-choice questions, ensuring a comprehensive understanding of the manufacturers' perspectives. Pre-testing was conducted with a small sample of industry experts to refine the questions and ensure clarity and relevance.

4.2 Sample Size and Sampling Methods

The sample size of 185 manufacturers was determined based on a stratified random sampling approach. This approach was chosen to ensure that the sample accurately represented the diversity within the Indian manufacturing sector, particularly in terms of company size, industry sector, and geographic location. Stratification allowed for the inclusion of manufacturers from various subsectors, such as automotive, aerospace, and tooling, which are key areas of interest for this study.

The sample size of 185 was justified through power analysis, which indicated that this number would provide sufficient statistical power to detect significant relationships between the variables of interest. Additionally, this sample size was deemed adequate to ensure representativeness and generalizability of the findings to the broader manufacturing population in India.

4.3 Data Collection Sources

Primary data was collected directly from the 185 manufacturers through the structured questionnaires. The questionnaires were distributed electronically, and follow-up interviews were conducted with a subset of respondents to gather more detailed insights. The use of electronic distribution was aimed at maximizing response rates and ensuring a broad geographic reach.

Secondary data was sourced from a variety of reliable channels, including industry reports, government publications, academic journals, newspapers, and articles from reputable internet media outlets. The secondary data provided a contextual background for the study and supplemented the primary data by offering insights into global trends, technological advancements, and market dynamics relevant to the adoption of multifiber reinforced ABS composites.

4.4 Statistical Techniques

The study employed several statistical techniques to analyze the collected data, including regression analysis, correlation, standard deviation (SD), and mean. These techniques were selected for their ability to test the study's hypotheses and explore relationships between variables:

- **Regression Analysis:** This was used to identify the factors that significantly influence the adoption of multifiber reinforced ABS composites. It helped in understanding the predictive power of variables such as company size, sector, and existing use of composites.
- **Correlation Analysis:** This technique was applied to examine the strength and direction of the relationships between different research variables, such as the relationship between company size and the perceived benefits of ABS composites.

• **Standard Deviation (SD) and Mean:** These descriptive statistics were used to summarize the data, providing an overview of the central tendencies and variability within the responses. The mean helped in understanding the average perception or adoption rate, while the standard deviation provided insights into the dispersion of the responses.

4.5 Cross-Sectional Study Design

The research employed a cross-sectional study design, where data was collected at a single point in time. This design was chosen because it allows for the efficient collection of data from a large sample, enabling the researchers to capture a snapshot of the current state of the industry regarding the adoption of multifiber reinforced ABS composites.

5. Results

Table 5.1: Demographic Characteristics

Sr. No.	Demographic Characteristics	Category	N	%
1	**Gender**	Male	98	53.0%
		Female	87	47.0%
2	**Age**	18-24 years	42	22.7%
		25-34 years	57	30.8%
		35-44 years	42	22.7%
		Above 45 years	44	23.8%
3	**Type of Residence**	Rural	83	44.9%
		Urban	102	55.1%
4	**How many employees work at your manufacturing facility?**	Large (501+ employees)	61	33.0%
		Medium (51-500 employees)	57	30.8%
		Small (1-50 employees)	67	36.2%
5	**What is the average annual production volume of products manufactured by your company using composite materials?**	11-15%	37	20.0%
		16-20%	35	18.9%
		5-10%	44	23.8%
		Less than 5%	31	16.8%
		More than 20%	38	20.5%
6	**Is your company currently engaged in the application of an Additively Manufactured multifiber-reinforced ABS Composite?**	No	85	45.9%
		Yes	100	54.1%

Table 5.1 shows the Demographic Characteristics of the respondents in the context of their Gender, Age group, Residence, employee working at manufacturing facility, average annual production, and Company engagement in the application of an Additively Manufactured multifiber-reinforced ABS Composite. According to Table 1, out of 185 respondents, 53.0% are male and 47.0% are females. The maximum number (57) of respondents are from the age group of 25-34 years, i.e., 38.8%. The greatest figure (102) of respondents resides in Urban areas, i.e., 51.1%. The further table shows the number of respondents working at manufacturing facilities, i.e. maximum number (67) are small employees (1-50 employees), i.e.36.2%. The Maximum number (44) of Average annual production by the respondents in 5-10%, i.e. 23.8% and the maximum number of respondents (100) of the company responded about engagement in the application of an Additively Manufactured multifiber-reinforced ABS Composite as Yes, i.e.54.1%.

Results based on Hypothesis

H0: There is no significant difference in the technological readiness among manufacturers concerning the adoption of Additively Manufactured Multi-fibre Reinforced ABS Composite into their production processes.

H1: There is a significant difference in the technological readiness among manufacturers concerning the adoption of Additively Manufactured Multi-fibre Reinforced ABS Composite into their production processes.

Table 5.2: Paired Samples Statistics

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Technological Readiness among Manufacturers	17.16	185	4.33	0.31865
	Adoption of ABS Composite into Production Processes	17.88	185	4.49	0.33014

The statistics for the paired samples are shown in Table 5.2. A mean of 17.16 for technological readiness and a mean of 17.88 Garg et al.
for the adoption of ABS composite into production processes were observed in pair 1. When looking at the average of the two sets, it is clear that manufacturers are more concerned with the use of ABS composite in their production processes than with their level of technological readiness.

Table 5.3: Paired Samples Correlations

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	Technological Readiness among Manufacturers & Adoption of ABS Composite into Production Processes	185	0.378	0.000

The variables from Pair 1 are discussed in Table 5.3, which is the paired samples correlation table. With a significance level below 0.05 (i.e., 0.000), table 5.3 demonstrates a positive link between manufacturers' technological readiness and the use of ABS composite into production processes.

Table 5.4: Paired Samples Test

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Technological Readiness among Manufacturers - Adoption of ABS Composite into Production Processes	-.71892	4.92409	.36203	-1.43318	-.00466	-1.986	184	.049

The inferential t-test statistics and the presence or absence of a statistically significant difference between the conditions are displayed in Table 5.4, which is the paired sample test table. Table 5.4 shows that from Pair 1, One may deduce that online education and traditional teaching are significantly related (significance value is less than 0.05, i.e., 0.000).

H0: Technological constraints and workforce training do not significantly contribute to the challenges and barriers faced by manufacturers in adopting the Additively Manufactured Multi-fibre Reinforced ABS Composite.

H2: Technological constraints and workforce training significantly contribute to the challenges and barriers faced by manufacturers in adopting Additively Manufactured Multi-fibre Reinforced ABS Composite.

Table 5.5: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.397[a]	.158	.153	3.59524
a. Predictors: (Constant), Technological Constraints and Workforce Training				

The model summary is defined in Table 5.5, which shows a strong degree of correlation. Manufacturers' Obstacles and Challenges in Adopting ABS Composite, the dependent variable, explains a significant portion of the total variation, with an R-value of 0.397 for the simple correlation. Results can be explained by utilizing the independent variable.

Table 5.6: ANOVAa

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	442.377	1	442.377	34.225	.000[b]
	Residual	2365.407	183	12.926		
	Total	2807.784	184			
a. Dependent Variable: Challenges and Barriers Faced by Manufacturers While Adopting ABS Composite						
b. Predictors: (Constant), Technological Constraints and Workforce Training						

In this sixth table of the analysis of variance, one can see how well the regression model fits the data or makes a prediction about the dependent variable. In this table, one can see that the dependent variable is well predicted by the regression model. Overall, the regression model predicts the outcome variable statistically substantially (i.e., it is a good match for the data) since the 0.000 value is less than 0.05, which signifies statistical significance.

Table 5.7: Coefficients

Coefficients[a]						
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11.177	1.209		9.241	.000
	Technological Constraints and Workforce Training	.414	.071	.397	5.850	.000
a. Dependent Variable: Challenges and Barriers Faced by Manufacturers While Adopting ABS Composite						

Table 5.7 of the coefficients gives us the data one needs to forecast how "Technological Constraints and Workforce Training" will play out in the model and to find out if "Challenges and Barriers Faced by Manufacturers While Adopting ABS Composite" makes a difference.

H0: There is a significant impact of Additively Manufactured Multi-fibre Reinforced ABS Composite on the performance and quality of products is not significantly different from traditional materials.

H3: There is a significant impact of Additively Manufactured Multi-fibre Reinforced ABS Composite on the performance and quality of products is significantly different from traditional materials, including observed improvements or challenges.

Table 5.8: Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.366[a]	.134	.129	3.29487
a. Predictors: (Constant), Adoption of ABS Composite into Production Processes				

There is a strong degree of connectivity, as seen in Table 5.8, which specifies the model summary. A simple correlation R-value of 0.336 indicates that the independent variable can account for a significant portion of the variation in the dependent variable, Performance and Quality, when comparing Composite and Traditional Materials (Including Observed Improvements or Challenges).

Table 5.9: ANOVAa

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	307.179	1	307.179	28.295	.000[b]
	Residual	1986.680	183	10.856		
	Total	2293.859	184			
a. Dependent Variable: Performance and Quality between the Composite and Traditional Materials (Including Observed Improvements or Challenges)						
b. Predictors: (Constant), Adoption of ABS Composite into Production Processes						

Table 5.9 of the analysis of variance (ANOVA) tells how well the regression model fits the data or makes a dependent variable prediction. In this table, one can see that the dependent variable is well predicted by the regression model. Overall, the regression model predicts the outcome variable statistically substantially (i.e., it is a good match for the data) since the 0.000 value is less than 0.05, which signifies statistical significance.

Table 5.10: Coefficients[a]

Coefficients[a]						
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	11.402	.997		11.439	.000
	Adoption of ABS Composite into Production Processes	.288	.054	.366	5.319	.000

a. Dependent Variable: Performance and Quality between the Composite and Traditional Materials (Including Observed Improvements or Challenges)

In order to forecast the impact of the "Adoption of ABS Composite into Production Processes" and ascertain the statistical significance of the "Performance and Quality between the Composite and Traditional Materials (Including Observed Improvements or Challenges)" according to the model, one can refer to the data provided by the Coefficients Table 5.10.

5.1 Interpretation of Key Statistical Findings

5.1.1 Technological Readiness and Adoption of ABS Composites

The paired samples statistics (Table 5.2) show a mean score of 17.1568 for technological readiness and 17.8757 for the adoption of ABS composites into production processes. This indicates that manufacturers perceive the adoption of ABS composites to be slightly ahead of their technological readiness. The paired samples correlation (Table 5.3) shows a significant positive correlation ($r = 0.378$, $p < 0.001$), suggesting that as technological readiness increases, so does the adoption of ABS composites.

The paired samples test (Table 5.4) reveals a significant difference between technological readiness and the adoption of ABS composites ($t(184) = -1.986$, $p = 0.049$). This finding supports the alternative hypothesis (H1) that there is a significant difference in technological readiness among manufacturers concerning the adoption of ABS composites. The practical implication is that while manufacturers may be increasingly adopting ABS composites, there remains a gap in technological readiness that needs to be addressed to ensure smooth integration into production processes.

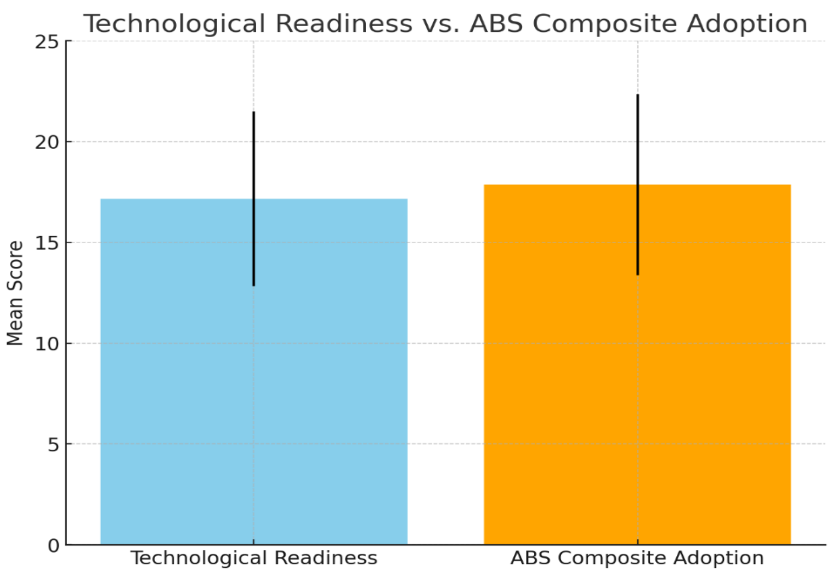

Fig. 5.1 The graph below illustrates the difference in mean scores for technological readiness and adoption of ABS composites.

5.1.2 Challenges and Barriers Faced by Manufacturers

The model summary (Table 5.5) shows an R-value of 0.397, indicating a moderate correlation between technological constraints, workforce training, and the challenges and barriers faced by manufacturers in adopting ABS composites. The ANOVA (Table 5.6) confirms that this relationship is statistically significant ($F(1, 183) = 34.225$, $p < 0.001$), suggesting that these factors contribute significantly to the challenges faced by manufacturers.

The coefficients table (Table 5.7) reveals that both technological constraints and workforce training are significant predictors of the challenges faced by manufacturers ($B = 0.414$, $t = 5.850$, $p < 0.001$). This supports the alternative hypothesis (H2) that technological constraints and workforce training significantly contribute to the challenges and barriers in adopting ABS composites. These findings highlight the need for targeted interventions in training and technological upgrades to mitigate these challenges.

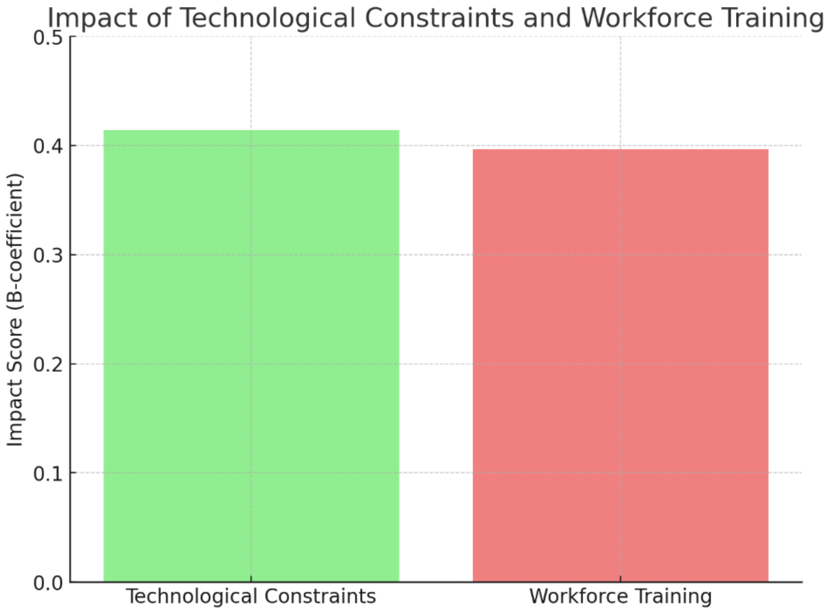

Fig. 5.2 The bar chart below displays the impact of technological constraints and workforce training on the challenges faced by manufacturers.

5.1.3 Impact of ABS Composites on Product Performance and Quality

The model summary (Table 5.8) shows an R-value of 0.366, indicating a moderate correlation between the adoption of ABS composites and improvements in product performance and quality. The ANOVA (Table 9) demonstrates that the regression model significantly predicts the dependent variable ($F(1, 183) = 28.295$, $p < 0.001$). This suggests that the adoption of ABS composites is significantly associated with improved product performance and quality compared to traditional materials.

The coefficients table (Table 5.10) further supports this, showing that the adoption of ABS composites has a significant positive impact on performance and quality ($B = 0.288$, $t = 5.319$, $p < 0.001$). This finding supports the alternative hypothesis (H3) that there is a significant impact of ABS composites on the performance and quality of products, indicating that these materials can offer substantial advantages over traditional materials.

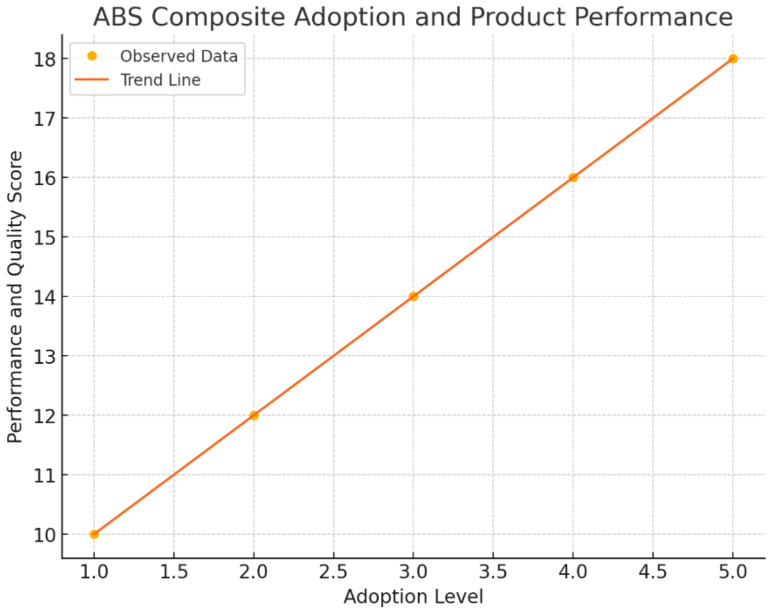

Fig. 5.3 The line graph below shows the relationship between ABS composite adoption and improvements in product performance and quality.

5.2 Summary of Findings

The statistical analysis reveals that while there is a growing adoption of ABS composites, technological readiness remains a concern. The challenges and barriers related to technological constraints and workforce training are significant and need to be addressed to facilitate wider adoption. Additionally, the adoption of ABS composites is positively correlated with improvements in product performance and quality, suggesting that these materials have the potential to significantly enhance manufacturing outcomes.

These findings underscore the importance of investing in technological upgrades and workforce training to fully leverage the benefits of ABS composites in the advanced engineering, tooling, and electric vehicle industries in India.

6. Finding and Discussion

6.1 Linking Findings to Literature Review

The study's findings resonate with the evolving understanding of composite materials as discussed in Section 2. For instance, Alagesan (2020) highlighted the innovative approaches to hybrid composites, which align with the current study's exploration of multifiber-reinforced ABS composites. The emphasis on sustainable and recyclable alternatives to conventional synthetics is echoed in the present study's findings, where manufacturers indicated a growing preference for composites that offer both mechanical strength and environmental benefits.

The study's examination of technological readiness (Tables 5.2 and 5.3) and the impact of ABS composites on product performance (Tables 5.8, 5.9, and 5.10) ties directly to the technological challenges and applications in the automotive and aerospace sectors discussed by Chauhan et al. (2022) and Lotfi et al. (2021). The significant correlation between technological readiness and ABS composite adoption suggests that, as Yi et al. (2019) observed, overcoming technological barriers is crucial for widespread adoption. This finding also supports the literature on the need for industry players to invest in digital transformation and workforce training (Wen et al., 2022) to fully leverage the benefits of additive manufacturing.

Furthermore, the study's results regarding the challenges and barriers faced by manufacturers (Table 5.7) align with Niaki et al. (2019), who emphasized the importance of addressing technological constraints and workforce training to enhance the sustainability and efficiency of additive manufacturing processes. These findings contribute to the broader discourse on optimizing composite materials for large-scale industrial applications.

6.2 Broader Implications for the EV Industry

The findings have significant implications for the EV industry in India and beyond. As Colorado et al. (2020) discussed, the long-term viability of additive manufacturing is closely tied to the circular economy and material optimization. The present study's findings reinforce this, showing that multifiber-reinforced ABS composites can play a crucial role in enhancing the performance and sustainability of EV components. The strong correlation between the adoption of ABS composites and improved product performance suggests that these materials could help address some of the current limitations in EV manufacturing, such as weight reduction and durability.

Additionally, the study's focus on the tooling and advanced engineering sectors highlights the potential for these composites to drive innovation in EV production processes. By improving the mechanical properties of tooling materials, manufacturers can achieve greater precision and efficiency, ultimately leading to cost savings and higher-quality products. This finding supports the broader trend toward integrating advanced composites into the production of EVs, as discussed in the literature.

6.3 Future Research Directions

Based on the study's findings, several specific areas for future research emerge:

• **Technological Integration:** Future studies should explore how manufacturers can better integrate new technologies with existing production processes to enhance the adoption of multifiber-reinforced ABS composites. This includes investigating the role of digital tools and automation in streamlining composite manufacturing.

• **Long-Term Durability:** There is a need for research into the long-term durability of ABS composites under different environmental conditions, particularly in high-stress applications such as automotive and aerospace components.

• **Sustainability and Circular Economy:** Further research is needed to examine the lifecycle impacts of ABS composites, including recycling and end-of-life disposal, to support the development of more sustainable manufacturing practices.

• **Workforce Training and Skill Development:** Investigating the specific training needs and skill gaps among manufacturing workers in relation to additive manufacturing and composite materials could inform targeted educational initiatives.

6.4 Limitations and Potential Biases

While the study provides valuable insights, it is not without limitations. The sample size, though justified through stratified random sampling, may not fully capture the diversity of the Indian manufacturing sector. Additionally, the reliance on self-reported data through questionnaires introduces the potential for response bias, where participants may overestimate their technological readiness or the benefits of ABS composites.

Moreover, the cross-sectional design of the study limits the ability to assess changes over time, such as the evolving perceptions of manufacturers or the long-term impact of adopting ABS composites. Future longitudinal studies could provide a more dynamic understanding of these factors.

Finally, the study's focus on manufacturers in India may limit the generalizability of the findings to other contexts, particularly in regions with different technological infrastructures or regulatory environments. Comparative studies across different countries could help to validate the findings and explore how regional differences influence the adoption of multifiber-reinforced ABS composites.

7. Conclusion

The research paper "Exploring Manufacturer Perspectives: The Market Viability and Applications of Multifiber Reinforced ABS Composite in India’s Advanced Engineering, Tooling, and Electric Vehicle Industry with Additive Manufacturing" provides valuable insights into the adoption and application of multifiber-reinforced ABS composites within the Indian EV industry. The study highlights key findings related to market dynamics and the challenges manufacturers face when integrating this advanced material into their production processes.

Key insights include the strong correlation between workforce training, technological readiness, and the successful adoption of ABS composites. The study also underscores the positive impact of ABS composite adoption on product performance and quality compared to traditional materials. These findings are crucial for manufacturers, policymakers, and industry stakeholders, offering guidance on how to address the obstacles and capitalize on the opportunities associated with using multifiber-reinforced ABS composites.

Practical Implications for Stakeholders in the EV Sector

For stakeholders in the EV sector, these findings suggest several practical implications:

• **Investment in Workforce Training:** To fully realize the benefits of multifiber-reinforced ABS composites, there is a need for targeted investments in workforce training. By equipping employees with the necessary skills and knowledge, manufacturers can enhance their technological readiness and improve the adoption rate of advanced composites.

• **Technological Upgrades:** Addressing technological limitations is essential for integrating ABS composites into production processes. Stakeholders should consider investing in digital transformation and advanced manufacturing technologies to overcome these barriers and enhance production efficiency.

• **Product Quality and Innovation:** The positive impact of ABS composites on product performance and quality presents an opportunity for innovation in the EV sector. Manufacturers can leverage these materials to develop lighter, stronger, and more durable components, which are critical for improving the efficiency and sustainability of electric vehicles.

Overall, this study provides a foundation for future advancements in additive manufacturing and materials research, particularly in the context of India's growing EV industry. By addressing the identified challenges and embracing the opportunities presented by multifiber-reinforced ABS composites, stakeholders can drive sustainable growth and enhance their competitive position in the global market.

8. Implication, Limitations, and recommendations for further studies

For many parties involved, the study's findings in "Exploring Manufacturer Perspectives: The Market Viability and Applications of Multifiber Reinforced ABS Composite in India’s Advanced Engineering, Tooling, and Electric Vehicle Industry with Additive Manufacturing" have vital implications. For starters, knowing the market potential and uses of multifiber reinforced ABS composite will help producers in India's electric vehicle (EV), advanced engineering, and tooling industries cut costs. Manufacturers may make better judgments about incorporating this composite material into their manufacturing processes if they have a good grasp of the technological readiness and difficulties of doing so. It has the potential to improve product performance and quality.

Limits should be recognised. Primarily, the study's results can be skewed depending on how many manufacturers were included in the sample and how representative they were. Further, it is not possible to draw any firm conclusions about cause and effect because the research was cross-sectional. Furthermore, there is a risk of response bias and subjective interpretations when data is relied upon

from self-reported sources, like surveys. Additionally, the study only looked at the Indian environment. Therefore, its findings might not apply to other places or businesses alike.
Multiple suggestions may be made to overcome these constraints and direct future studies. First, the advanced engineering, tooling, and electric vehicle (EV) industries in India might benefit from longitudinal studies that track the industry's use of multifiber-reinforced ABS composite over time. In addition to quantitative data, qualitative research methods like focus groups or interviews might provide a more in-depth look at the experiences and viewpoints of manufacturers. To gain a more comprehensive knowledge of the variables impacting the adoption of composite materials, comparative studies conducted across several areas or sectors might be useful. Ultimately, a thorough evaluation of the possible advantages and disadvantages for India's industrial industry and society at large might be achieved by investigating the monetary, ecological, and social consequences of utilising ABS composites.

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