STUDY AND FABRICATION OF OPTIMIZED DIP RESIN BATH

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Abstract

This paper discusses, the analysis of the design considerations for a dip resin bath utilized in filament winding machines, focusing on parameters such as heat and viscosity. Integration of these parameters is crucial for optimizing the performance of the resin bath. By examining the complex relationship between heat and viscosity, this study sheds light on the detailed engineering required for efficient resin impregnation. The paper also highlights the importance of dip resin baths across multiple industries, including aerospace and automotive. The resin bath plays a pivotal role in enhancing the structural integrity and performance of materials opening doors for further development and application of composite materials across various fields. Through this exploration, the paper highlights the significance of resin baths in facilitating the widespread adoption of filament winding technology across industrial sectors.

Keywords:
Dip Resin Bath, Filament Winding, Heat, Viscosity, Composite Materials, Industrial Applications.

I. Introduction

1.1 Resin bath process

The utilization of composite materials has witnessed a significant surge across industries due to their exceptional mechanical properties, lightweight nature, and versatility. Within the realm of composite manufacturing processes, filament winding stands out as a prominent technique for fabricating cylindrical structures with enhanced strength-to-weight ratios. The resin bath is a critical component of the filament winding process.

One of the primary functions of the dip resin bath is to provide a controlled environment for the resin application process. It involves maintaining optimal conditions such as temperature, viscosity, and resin flow rate to achieve uniform wetting of the fibres and facilitate proper resin impregnation.

The design of the dip resin bath contains various aspects, including material selection, geometry, and heating mechanisms. The choice of materials depends upon factors such as chemical compatibility, resistance to corrosion, and durability.

Temperature control is a critical aspect in the design of resin baths, as it directly impacts resin viscosity and curing kinetics. Precise temperature regulation ensures that the resin remains within its specified viscosity range for optimal impregnation of the fibres. Heating systems such as electric heaters, immersion heaters, or circulating hot oil are employed to maintain consistent temperatures throughout the bath.

1.2 Types of resin Bath

1. Dip Resin Bath: (Traditional method) Fibres are passed through the resin tank for impregnation.

2. Roller Resin Bath: Uses rollers for even resin coating. This type of resin bath is suitable for continuous production.
3. Spray Resin Bath: Atomized sprays apply resin for controlled deposition. It is ideal for precise applications.
4. Curtain Coating Resin Bath: The resin dispensed over the substrate through curtain flow ensures consistent coverage.
5. Vacuum Resin Infusion (VRI) Bath: Resin infused into dry fibres under vacuum pressure results in void-free parts.
6. Pressure Resin Infusion (PRI) Bath: Resin forced into fibres under pressure ensures thorough impregnation.
7. Continuous Resin Impregnation (CRI) Bath: Features continuous resin flow for rapid impregnation, suitable for high-volume production.

1.3 Significance of Optimization

1. Heat: Heat plays a critical role in resin baths as it directly influences the viscosity of the resin. Controlling the temperature ensures that the resin remains within the desired viscosity range for optimal impregnation of fibres. Higher temperatures decrease the viscosity, making the resin more fluid and easy to penetrate the fibres, while lower temperatures increase viscosity, which can hinder resin flow. Therefore, precise heat management is essential to maintain consistency in resin application and achieve uniform distribution throughout the material.
2. Temperature Control: Temperature control systems are integral to resin baths to maintain uniform resin properties. Fluctuations in temperature can lead to variations in resin viscosity, curing kinetics, and overall process performance. By implementing precise temperature control mechanisms, we can regulate resin characteristics according to our requirements, such as resin type, fibre type, and processing speed. It enhances the quality and reliability of the products and enables tighter control over the process, resulting in improved repeatability and efficiency.
3. Viscosity: Viscosity is a parameter that governs resin flow behaviour and impregnation capability. The viscosity needs to be maintained precisely to ensure proper penetration of fibres during fabrication. Optimal viscosity ensures uniform resin distribution, minimizes resin waste, and prevents defects such as dry spots or resin-rich areas in the final product.

By adjusting the resin formulation and process parameters, we can tailor viscosity to meet specific application requirements and achieve desired properties. Furthermore, monitoring and adjusting viscosity during production enable real-time optimization of resin bath performance, leading to enhanced reliability and quality.

1.4 Relevant technologies for the implementation of resin bath

1. Filament Winding: Resin baths are a critical component in filament winding machines for manufacturing structures such as pipes, tanks, and pressure vessels. They impregnate continuous fibres with resin before winding them onto a mandrel or form, ensuring uniform resin distribution and bonding throughout the part.
2. Pultrusion: In pultrusion processes, resin baths impregnate fibres with resin before they get pulled through a heated die to cure and form continuous profiles or rods. The resin bath ensures proper wetting of the fibres and facilitates resin impregnation for high-strength products.
3. Laminating: In laminating processes, layers of reinforcing materials, such as fibreglass or carbon fibre fabrics, are bonded with resin to form composite laminates. They provide a controlled environment for resin application, ensuring thorough impregnation and consolidation of the laminate stack.
4. Composite Moulding: Resin baths are used in various composite moulding techniques, including compression moulding, injection moulding, and resin transfer moulding (RTM). They facilitate the

impregnation of dry fibre preforms or fabrics with resin before moulding into complex shapes under heat and pressure.

5. Composite Coating: Resin baths are utilized in coating applications where substrates are coated with resin to provide protection, insulation, or decorative finishes. They enable precise control over resin application parameters, ensuring uniform coating thickness and coverage for various substrates and applications.

6. Fibre Reinforced Polymer (FRP) Manufacturing: Resin baths are integral for fibre-reinforced polymer (FRP) composites in construction, automotive, marine, and aerospace industries. They facilitate the impregnation of fibres with resin to create lightweight, high-strength materials for structural and non-structural applications.

II. Current Challenges

1. Resin Waste Reduction: Challenges in minimizing excess resin and developing recycling systems.
2. Uniform Resin Distribution: Achieving consistent resin distribution throughout the reinforcement material is essential for producing high-quality composite parts. Challenges involve dry spots or resin-rich areas and addressing variations in resin flow.
3. Temperature Control: Maintaining precise temperature within the resin bath is critical for controlling resin viscosity. Challenges include managing heat distribution, minimizing temperature fluctuations, and accommodating different resin types.
4. Viscosity Control: Controlling resin viscosity is essential for the impregnation of fibres and resin flow behaviour. Challenges include maintaining viscosity within optimal ranges and addressing variations in viscosity caused by temperature changes.
5. Process Automation and Control: Automation and control systems are necessary for optimizing resin bath processes, but challenges exist in implementing reliable and efficient automation solutions. Challenges include integrating sensors and actuators for real-time monitoring and control, developing predictive algorithms for process optimization, and ensuring system reliability and robustness.
6. Quality Assurance and Inspection: Ensuring part quality and compliance with standards.
7. Environmental and Health Considerations: Minimizing emissions and ensuring safe handling.

2.1 Effect of Heat

1. Viscosity: Heat impacts the viscosity of the resin. Higher temperatures typically lead to lower viscosity. Lower viscosity resin flows more easily, facilitating the impregnation of fibres and promoting uniform distribution throughout the reinforcement material. However, excessively high temperatures can cause the resin to become too thin and lead to dripping.
2. Resin Cure Rate: Temperature affects the polymerization timing and solidification of the resin. High temperatures generally accelerate curing, reducing cycle time and increasing production efficiency. Conversely, lower temperatures slow- down curing, which may be advantageous for processes requiring extended working times or for controlling exothermic reactions.
3. Resin Stability: Heat can impact the stability and shelf-life of resin materials. Elevated temperatures can accelerate resin degradation, leading to changes in chemical composition, reduced pot life, and compromised performance. Proper temperature control is required to maintain material integrity during storage and processing.
4. Material Compatibility: Heat can affect the compatibility of resin materials with other components in the system, such as fibres, additives, or mould materials. Thermal expansion and contraction may cause dimensional changes or stresses within the structure, potentially leading to defects or reduced mechanical properties.
5. Energy Consumption: Heat-intensive processes consume significant energy, impacting operational costs and environmental sustainability. Efficient heating systems, insulation, and temperature control strategies are essential for minimizing energy consumption and optimizing process efficiency.

2.2 Effect of Viscosity

1. Impregnation Efficiency: Viscosity directly influences how easily the resin can penetrate and saturate the fibres. Lower viscosity resins flow more readily, allowing for quicker and more thorough impregnation of the fibres. Contrarily, higher viscosity resins may have difficulty penetrating the fibres, which may cause incomplete wetting and potential voids or dry spots in the final composite product.
2. Resin Flow Rate: The viscosity of the resin determines its flow behaviour within the resin bath and during subsequent processing steps. Lower-viscosity resins have higher flow rates and faster processing times. Controlling viscosity is crucial for regulating the resin flow rate to ensure proper resin distribution and impregnation without excessive resin wastage or resin-rich areas.
4. Resin Cure Kinetics: The viscosity of the resin affects the rate at which it undergoes polymerization and solidification. Higher viscosity resins typically have slower cure kinetics, requiring longer processing time or higher temperatures to cure. Conversely, lower viscosity resins may cure more rapidly, which can be advantageous for reducing cycle time and increasing production.
5. Resin Bath Behaviour: Viscosity impacts the behaviour of the resin within the resin bath, including its flow dynamics, stability, and susceptibility to sedimentation or settling. Controlling viscosity ensures uniform resin distribution and prevents issues such as resin agglomeration or stratification within the bath, which can lead to process inconsistencies and product defects.

III. Fabrication:

3.1 Proposed solution and its effect

The Advanced Tapman 96 7E2 Temperature Controller controlled the temperature. The main features are

- 4 Digit 7 Segment display
- Two outputs
- Universal Input – TC/ RTD
- Heating or Cooling Control
- On-Off or Time proportional mode

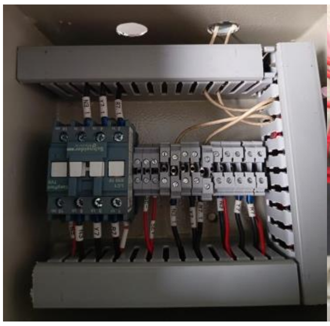

Fig 1: Elmex connectors

Fig 2: Tapman controller

Specifications:

Model	:	7E2	**Size**	:	96 x 96mm
Power Supply	:	220 V AC	**Mounting Type**	:	Panel Mount
Display	:	4 Digit 7 Segment RED LED Display	**Output**	:	Relay Contact, SSR Out put
Input Sensor	:	RTD, Thermocouple -J,K,E,T			

The k-type thermocouple is used with the temperature with Tapman 96 7E 2 to measure the temperature and provide feedback. The wiring and the control unit are separated and designed modular to facilitate the ease of repairing and upgrading. The contactors of suitable amperes are connected.

Elmex connectors are for wire management and connections. This arrangement is inside a ceramic control box with proper insulation and cooling installations.

Advanced manufacturing techniques were opted to eliminate any internal stresses arising during the fabrication, which could have led to fatal leaks and accidents.

The heating system was placed just below the resin tub and insulated as per the design to eliminate heat losses to increase efficiency and reduce the variability of the parameters. The system is insulated using appropriately thick glass wool while maintaining a safe distance from the heating element already considered while designing the system. The resin tub and heating systems are assembled precisely to prevent any air gaps or leaks into the surroundings, utilizing fasteners and insulated gap fillers for a secure fit.

This system was mounted on a height-adjustable base designed specially to facilitate the variation in the height to contribute to the variation of tension depending on the requirement.

Fig 3: Fabricated resin bath

3.2 Result of the proposed solution

The system underwent testing and demonstrated remarkable efficiency, exhibiting a reduced heat loss percentage of 41.413% compared to the previous 54.96%. This improvement led to enhancements in various parameters like energy consumption, uniform resin distribution, viscosity, and overall quality. The temperature control using the temperature controller played a vital role in the process by constantly taking feedback from the thermocouple installed in the resin tub and altering the power to the heating element (deviation of +/-2 degrees Celsius). The gap between the resin tub and the heating system is minimized to prevent diffusion into the surrounding environment. The internal and external insulations and reflectors effectively kept the heat within the enclosed area. The absence of air gaps and leaks in the system contributed to its efficient performance.

Calculation parameters:

Material used: SS304
Thermal conductivity of SS304: 16.3 W/(m·K) or 9.4 BTU/(hr·ft·°F).
Surface area of contact: 1 Sq Feet
Average temperature difference: 90-95deg Celsius
Heating element: Nichrome wire
Power rating: 1000 watts
Glass wool insulation thickness: 10mm
Reflector: Aluminium foil of thickness 0.94 mils
Resin melting temperature: 120deg Celsius
Average room temperature: 27deg Celsius

IV. Possible future development

Further development in the experiment would be incorporating vacuum and enclosed chambers for the whole system and attempting to reduce losses via air and ease the temperature control with more advanced controllers.

Also, the incorporation of fully automated systems using the latest technologies to manipulate the process parameters like temperature, tension, viscosity etc. can be utilized and planned.

4.1 Advantages

1. Improved Energy Efficiency: By reducing heat loss, the resin bath process becomes more energy-efficient, resulting in lower energy consumption and reduced operating costs.
2. Enhanced Process Control: With less heat loss, it becomes easier to maintain consistent temperatures within the resin bath, leading to improved process control and more predictable outcomes.
3. Increased Production Throughput: Reduced heat loss means less energy waste, allowing higher production output without compromising product quality.
4. Minimized Environmental Impact: Lower energy consumption, reduced greenhouse gas emissions and environmental impact, aligning with sustainability goals.
5. Improved Material Quality: Better temperature control and low heat loss facilitate the resin bath process to produce materials with higher mechanical properties and dimensional stability.

4.2 Disadvantages

1. Initial Investment Cost: The increased insulation and better system controllers require upfront investment, increasing initial capital expenditures.
2. Maintenance Requirements: This requires ongoing maintenance and periodic inspections to ensure optimal performance.
3. Complexity of Implementation: It involves implementing complex insulation systems and upgrading equipment, requiring specialized expertise and resources.

4.3 Applications

1. Aerospace Industry: Resin bath processes with reduced heat loss for the manufacturing of lightweight components for aircraft, such as fuselage panels, wings, and interior structures.
2. Automotive Industry: Reduced heat loss in resin bath processes enables the production of high-performance materials for automotive applications, including body panels, chassis components, and interior trim.
3. Renewable Energy Sector: Resin bath processes with enhanced energy efficiency are well-suited for producing components for wind turbines, solar panel frames, and other renewable energy infrastructure.
4. Construction Sector: The construction industry can benefit from resin bath processes with reduced heat loss for manufacturing materials used in building facades, structural components, and infrastructure applications.
5. Marine Industry: Resin bath processes with enhanced temperature control and energy efficiency for the materials for marine vessels, including hulls, decks, and interior fittings.

V. Conclusion

In this research article, a brief explanation of a resin bath is given. The process parameters heat and viscosity are considered in fabrication and optimization of resin bath. The various components used in fabrication of resin bath were discussed along with the fabrication process. The advantages, disadvantages, future possibilities and the applications are presented in the paper.

5.1 Credit authorship contribution statement

Aditya Jhamwar: Team leader, research coordination, project conceptualization, designing, fabrication writing and editing. **Jyostna Sameeksha Dangeti**: Data collection, literature review, documentation integrity, fabrication. **Meesala Mounika**: Intermediate fabrication, process optimization, quality control. **Rayan Sheik**: Materials sourcing and procurement, inventory management, documentation assistance. **C.Sucharitha**: Guidance, mentorship, composite materials expertise. **P.Shashidar**: Guidance, mentorship, research methodology expertise. **K. Rajshekhar Reddy**: Workshop owner, mentor, and sponsor.

5.2 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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