TOWARDS RAPID ROBOTIC FIBRE PLACEMENT WITH IN-SITU ULTRA-VIOLET CURING

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Abstract

This paper presents a novel concept of Robotic Fibre Placement (RFP) incorporating ultra-violet (UV) in-situ curing (UV RFP). This concept is discussed in relation to current industrial RFP systems and research literature. Preliminary analysis shows that extremely rapid deposition rates could be achieved using high intensity UV in-situ curing. A method for the generation of the placement path from a CAD model of the mould to program code for the robot is also outlined.

1. Introduction

Fibre-reinforced polymer composites are lightweight materials that offer high specific strength and stiffness. The use of these materials for large automotive parts such as body structures would reduce vehicle weight. This would improve fuel efficiency, reduce harmful exhaust emissions and increase the viability of green power sources. Glass-fibre composites in particular can reduce environmental burden compared to metals (Puri and Compston, 2008). Composites manufacturing however, is often characterised by numerous processing stages, long cycle times, high scrap rates, hazardous chemical emissions and expensive capital equipment. Cleaner, quicker processes are required to increase their utilisation in high-volume industries (Bannister, 2001).

Robotic Fibre Placement (RFP) is an automated manufacturing process for composites. It uses the speed, accuracy and repeatability of industrial robots to place composite layers on moulds or mandrels to produce net-shape components. It has been used by the aerospace industry to place carbon-fibre prepreg layers. However, prepregs require a further thermal-cure stage under pressure in an autoclave. RFP requires rapid in-situ curing, where the composite is placed and cured in a single stage, to make it viable for high-volume industries. UV curing composites could be used to achieve this aim.

This paper reviews the current fibre placement systems. It then presents an RFP head design for in-situ UV curing, and a process model. An initial analysis of placement rates is also made. A method for placement path generation from a CAD model of the mould to program code for the robot is also outlined.

2. Background

2.1 Fibre Placement

Automated fibre placement processes were conceived by the aerospace industry to meet the throughput and quality demands for composite material manufacture. The technology is now one of the central composite manufacturing processes used today in aircraft manufacture and critical to the utilisation of composites in the design of future products (Grant, 2000; Tierney and Gillespie, 2003).

Typically, fibre tows are fed into an application head that is attached to the end of a manipulation device which accurately positions and lays the fibres onto the surface of a tool or mould in a controlled manner. The fibre tows are usually pre-impregnated with the matrix resin, which is heated to liquid state at the application point and compacted under pressure to produce tailored composites with defined and controlled fibre paths. Robotic fibre placement (RFP) improves accuracy and repeatability of fibre alignment while increasing throughput and reducing cycle costs. However, the need for RFP processes that use cheaper, faster, options that use cheaper materials and produce parts with greater throughput has been highlighted (Starnes *et al.*, 2006).

Experiments have produced accurate characterisation models of FP (Sonmez and Hahn, 1997). These models have shown the significant effect of the cure mechanism on the overall system and have been used to develop processing windows (Steeg *et al.*, 2006). The current focus of research uses heat curing and prepreg material supply. Due to the slow response time of thermal sources, path planning and start/stop functionality has been greatly limited in order to protect the tow against thermal degradation from overheating (Tierney and Gillespie, 2003). The design of FP units has also been limited due to the size and energy requirements of concentrated heat sources, and their damaging effects on equipment. The stability of the process temperature using convection sources has also been difficult to maintain.

Most commercial systems currently implemented run on a 5-axis gantry system. These systems have a large area footprint, are a considerable initial investment and have less than full flexibility in terms of DOF. Complex part manufacturing in FP terms requires small minimum radii and the ability to maintain normal contact to the mould through tight changes in geometry such as narrow concave channels and over small fillets. Current systems are usually designed for the manufacture of larger less complex parts meaning the physical size of the FP head is increased to handle higher forces, more material output and use a larger compaction roller. This philosophy limits the ability of these units to access tight corners and complex geometry.

2.2 Materials

Most RFP processes have been developed for expensive thermoset (epoxy) prepreg materials. Thermoset prepregs are heated to increase tack prior to placement. However, after placement, thermoset prepregs still require a thermal curing stage to fully consolidate the layers and maximise properties. Thermoset prepregs also require refrigeration and have a limited shelf life. This thermal curing often requires the use of an autoclave, greatly limiting the maximum dimensions of a single part, using a large amount of factory floor area and a large initial investment cost.

Thermoplastic prepregs (such as carbon-fibre/PEEK or glass-fibre/polypropylene) are an alternative to thermoset-based prepregs. Thermoplastics can be heated, consolidated under pressure and then cooled by the head (Starnes *et al.*, 2003). This gives a relatively quick processing time. Drawbacks are the high material costs, low operating temperatures of the materials and running costs of the gas heat torches.

In-situ FP combines the lay-up and curing steps of composite manufacture. In-situ curing through Electron Beam (EB) irradiation can be combined with automated fibre placement (Enders, 1991) to produce composites with superior mechanical properties compared to thermal cure composites (Goodman *et al.*, 2000). However, EB radiation poses a significant risk in the work environment. EB curing requires shielding around the work area, increasing the installation cost and decreasing floor space. The EB gun sub-assembly for RFP heads also makes the head size larger than ideal for complex part manufacturing. Therefore, industrial implementation of EB curing is unlikely.

There is potential for rapid in-situ curing of thermoset resin with UV radiation. Processing times of glass-fibre composites are orders of magnitude quicker than room temperature or thermal cure counterparts (Cvetanovska and Compston, 2004) with a relatively low power (400W) and low intensity UV light (2mW/cm^2). Mechanical properties are unaffected by layering and secondary bonding, and solvent emissions are reduced (Compston *et al.*, 2007). Furthermore, curing of the resin occurs only on exposure to UV. This allows time for precise fibre placement and orientation, complete wet out of fibres and removal of trapped air voids. The increased speed of UV curing, as well as convenient on demand control of initiation has potential for industrial RFP applications.

3. RFP Concept with In-Situ UV Curing

An industrial robot will be examined as a viable solution in the manipulation of the FP head offering a scalable and highly flexible solution to gantry setups. A UV light will be mounted within a specifically designed fibre placement head for cure exposure on the fly. The integrated model from which the experimental rig was designed is proposed in *Figure 1*.

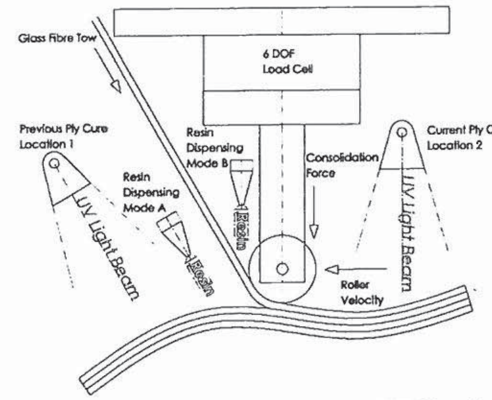

Figure 1. UV RFP Model including both resin dispensing and UV locations.

The functional design of this unit was based on benchmarking specifications formulated using Quality Functional Deployment (QFD). Using the thin 0.58mm thick glass roving/vinylester composite of the UV RFP project, it was found in preliminary experiments that full cure requires less than 10 second static exposure using a 400W mercury vapour lamp (MVL), at UVA wavelengths having 2.5mW/cm^2 intensity. Possible lay-up speeds of up to 300mm/sec are considered feasible using spot curing UV systems capable of ultra high intensities.

The system design for the experimental setup of this project is shown in *Figure 2*, including the acquisition of data and control of experimental parameters. Of particular significance, is the incorporation of the UV light and its control system. The incorporation of UV curing will offer higher lay-up speeds, the use of cheaper material supplies in situ curing that allows single processing of the part.

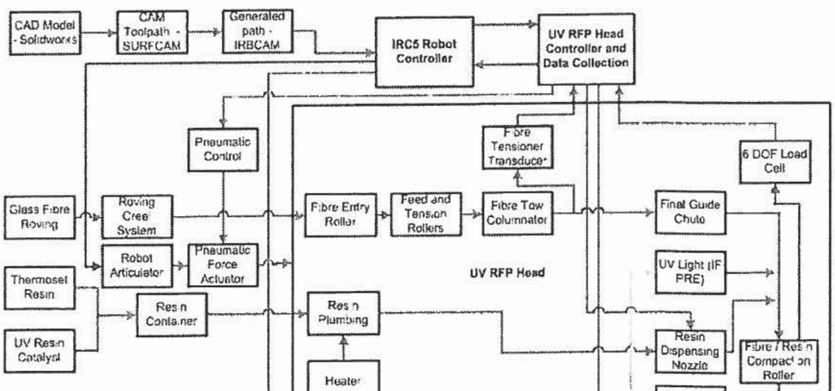

Figure 2. UV RFP System Design including Control paths

4. Placement Path Generation

The problems of path programming, planning and trajectory control from geometry and sensory feedback have been a major focus of robotic manipulation studies (Shirinzadeh *et al.*, 2003). These studies have provided solutions that utilise complex custom software that is highly specialised and limited in flexibility. The software is often highly cumbersome, expensive and often very slow to program needing specialised training. Custom control solutions of commercial RFP units currently available are the off-the-shelf solution, however these too are often characterised as highly inflexible, expensive and like the solutions of other studies slow and cumbersome in programming.

For the current project, a CAD-to-Robot commercial software solution has been identified to create paths in IRB Rapid code for ABB robots. Using a CAD file of the mould and a commercial CAM package, standard CAM APT-CL code is produced, such as in any CAM operation. The generation of the placement path for the robot however is generated by running the output APT-CL code through a post-processor, IRBCAM (IRBCAM, 2008), which converts the code into IRB standard robotic programming code. This process keeps the intelligence of path programming within the functionality of the CAM package used (e.g. SurfCAM) and allows a quick and highly flexible approach to converting CAD to the appropriate IRBCAM path program.

The time to generate a path using the IRBCAM post processor following CAM tool-path definition is dependant upon the size and geometric complexity of the CAD model. A path has been generated for composite placement on a simple mould, tool paths have been defined using a CAM package and the standard g-code output has then been run through the IRBCAM post processor producing the desired incremental lay-up paths for the robot. This process took less than 5 minutes, demonstrating the power of this commercial path generation solution.

5. Conclusion

A review of fibre placement processes has highlighted the potential for increased productivity, accuracy, repeatability in the manufacture of lightweight composite parts. For Robotic Fibre Placement (RFP), quicker material processing times are required in order to transfer these benefits to high-volume industries, such as automotive. This paper has presented a concept for a placement head design and process model for RFP with a UV-curing composite technology. Preliminary analysis shows rapid placement rates of 300mm/sec could be achieved using high intensity UV spot curing systems. The use of a UV-curing composite has been shown to reduce the complexity of the placement head design, reduce material costs and remove the need for additional part processing compared to current RFP processes. An efficient method of generating the placement path from a CAD model, for an ABB robot, has also been presented. Future work will focus on prototyping of the placement head and characterisation of the novel UV RFP process.

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