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AN APPROACH TO OPTIMIZE AUTOCLAVES FOR CURING FRP COMPOSITES

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Abstract

Composite materials due to their low weight, high specific strength, high stiffness & high specific thermal properties have always been a demanding material for advanced light aircrafts also the present trends indicate a huge demand for these composite components due to its high strength to its weight replacing the traditional metal parts in automotive and construction applications. These advanced fibre reinforced composites are cured using autoclaves under controlled cure parameters to achieve defect free high quality composite parts. Autoclave processing remains the backbone of advanced composite structure production and the productivity of a composite manufacturing industry rely on the utilisation of the Autoclaves. It is a need to utilize these autoclaves to its fullest volume so as to reduce the process cost per component. But at present these autoclaves are utilised only up to 40 - 50% of its volume result in under utilization and high processing cost. Hence producing high quality reliable composite materials in a large scale is a challenging task due to various manufacturing constraints. This paper focus on the issues and challenges considered for production scheduling and also a new approach called as the Autoclave Pull system is coined to optimise the autoclaves for curing composite materials. The results prove that the pull system is an efficient way to accomplish better productivity and to minimise the processing cost per part up to 50% and a significant increase in machine utilization by 30%.

Keywords: *Autoclaves, Composites, Curing, Optimisation, Prepeg.*

1. INTRODUCTION

Today every company strives to accomplish a bench mark in the global market with various strategies, intellectual ideas to improve the company's turnover, compelling for innovative ways to utilize the available resources effectively, adopting techniques like TPM, LEAN and 5s principles. Fabrication of advanced fibre composite components is highly expensive as it involves sequence of crucial processes. Production Scheduling is the heartbeat of every manufacturing industry and in the existing competitive scenario, an efficient production scheduling system streamlines the process & work flow to utilise the available facilities to its fullest capacity, which in turn results in high productivity and reduction of product cost.

Advanced fibre composite parts manufacturing environment involves specific and complex part routings through prepreg cutting and kitting, layup, autoclave curing, trimming, drilling, painting, inspection, assembly, etc. At present in the conventional system of manufacturing the parts are pushed in to the autoclaves for curing as and when the parts are ready after layup, even though the layup activities appears to be level-loaded, it is difficult to visualize end-to-end process. Hence it creates an in-efficient product sequence for down-stream operations and also takes more cycle time to get the end finished composite part. A typical manufacturing process flow of a composite part is as shown in the Fig.1.

The manufacturing process of a fibre composite part includes a sequence of operations like the prepregs stored in the deep freezers are moved to prepreg cutting area where it is allowed to attain room temperature and then these prepreg rolls are loaded to a sophisticated prepreg cutting machines to cut the prepreg layers in to desired orientations, shapes and size as per the requirement. Later these cut prepreg layers are moved to the layup area for stacking the layers over the tool as per the layup sequence and to the required thickness. After layup and vacuum bagging the bagged parts are loaded in to the autoclave depending on the availability of the autoclave, else the parts have to wait for autoclave cure slots. This is a major bottle neck in the traditional push system of manufacturing process. The cured parts are demoulded from the tools and are trimmed as per the drawing dimensions, later these parts are moved for DT/ NDT checks. After inspection and testing the parts are painted and sent to assembly.

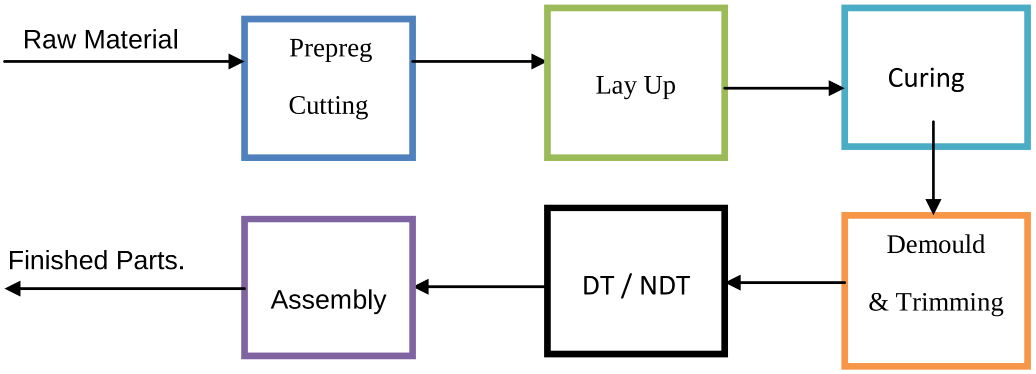

Fig. 1. Composite parts manufacturing process flow

Autoclaves have become indispensable tools/equipments for processing high quality polymer composite aerospace/aircraft structural components [1] and they can process wide variety of materials [2].Curing in an autoclave is a batch-process based on the material, cure-cycle, type of tool, etc, inefficient product sequencing, most often, confounds less batch quantity into the autoclave resulting in under utilization of machine capacity. An Activity-Based-Costing of autoclave reveals that irrespective of whether an autoclave is loaded to utilize 10% or 90 % of its capacity, an incremental change of only 5 % is observed in the operating cost. This highlights a direct bearing on the reduction of cost per part when an autoclave is utilized to its fullest capacity. Hence there is a vast scope to enhance the autoclave utilization and to increase the production with the existing facilities. A typical autoclave and the block diagram of the existing push system of manufacturing process are as shown in the fig. 2 & 3 respectively.

Data of ten batches cured in an autoclave was collected and analysed for the percentage autoclave volume consumed and the curing cost per component assuming the operating cost to remain constant for each cure batch. It was observed that the maximum autoclave volume utilised is only up to 50 percent as shown in the fig. 4 and the maximum number of parts cured in a cure batch was only 20 no. as shown in the fig. 5, this results in an average curing cost of Rs. 2500/- per part. This data indicates a scope for the improvement in the autoclave utilisation and in turn to enhance the production rate.

Fig.2. A typical Autoclave used to cure composite parts.

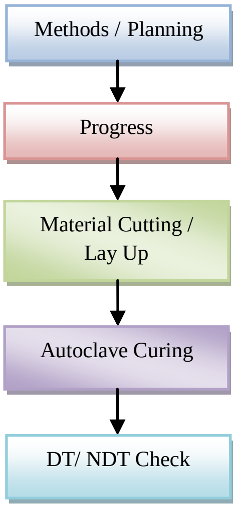

Fig.3 Push System of manufacturing process

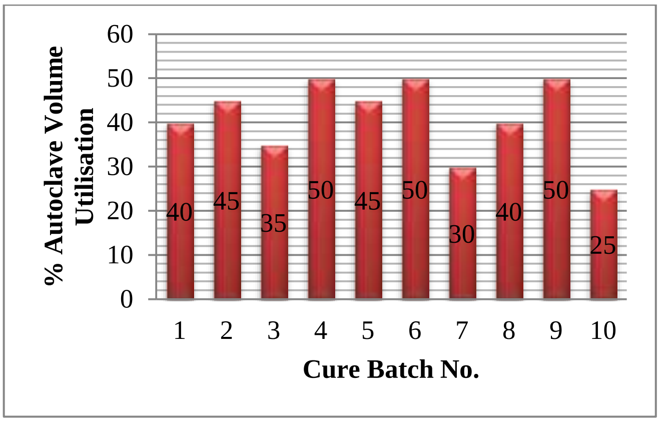

Fig.4 Autoclave volume utilisation for each batch

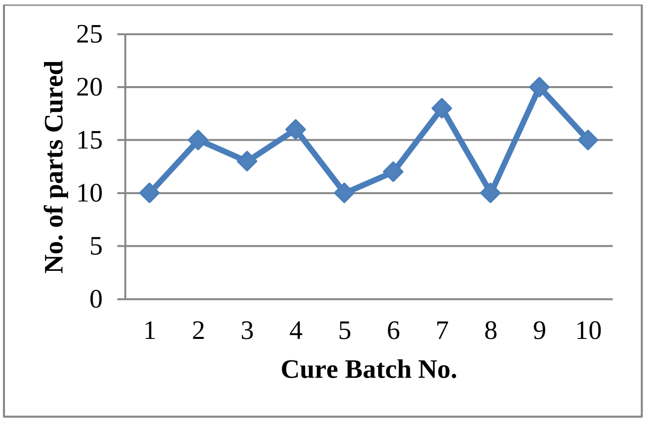

Fig.5 No. of parts cured in each batch

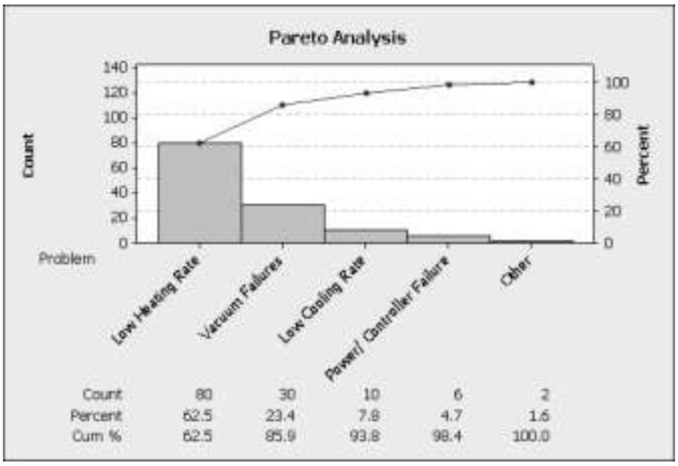

Fig.6 Pareto diagram of the rejection analysis

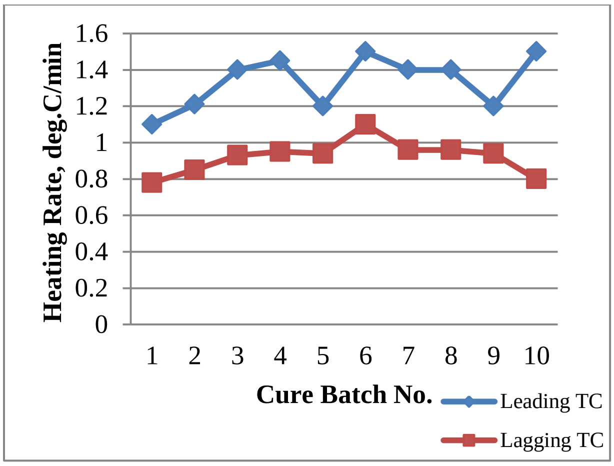

Fig.7 Heating rate variation b/w lagging & leading TC

However, the traditional push system of manufacturing composite parts leads to more curing snags which are analysed and plotted in a pareto diagram to identify the vital defects as shown the fig. 6 , the defects like variation in heating rates between the thick and thin parts as it is loaded in the same batch for curing[3] as shown in the fig.7, vacuum failures, variation in dwell time and in cooling rates and other deficiencies in curing that leads to higher rejection rates[4-5], also if the volume of production is less and requires only one or two parts to be loaded in a batch, again this situation leads to higher processing cost per part as the overall operating cost of the autoclave per batch is high and remains more or less same even if 30 parts are loaded in a batch. But the cure cost per part tends to decrease drastically if more number of parts is loaded in a batch.

2. AUTOCLAVE PULL SYSTEM

A pull system is nothing but an autoclave in a composite manufacturing centre pulls and drives the whole production synchronizing all the process right from material cutting to offering the parts to inspection instead of planning to push the parts in to an autoclave for curing as the part gets ready after layup. It is similar to a railway or a flight reservation system where the passengers need to book in advance for a flight on a particular time and date. In this case the autoclaves are treated as a flight and the parts waiting for curing as the passengers that needs to be scheduled in an efficient way to maintain the proper work flow and to enhance the autoclave utilisation. But there are few constraints which need to be addressed to optimise the production schedule to implement the autoclave pull system.

2.1 ISSUES & CHALLENGES

The vital issues and challenges to overcome like 1. Parts are fabricated with different prepreg materials that call for different cure cycles and to be cured in different batches[6]. 2. The tools used for layup are made of different materials and tends to vary the heat up rates due to their difference in thermal conductivity. 3. Parts fabricated are of different type like monolithic and sandwich that requires different cure parameters for curing in an autoclave. 4. Sandwich parts are made of foam or low density core that requires different cure cycles. 5. Autoclave size and the volume are constant cannot be altered. 6. Thermocouple ports used to sense the temperatures are limited 7. Vacuum suction and sensing ports are limited. 8. Close and efficient monitoring of autoclaves during curing process. 9. Variation in tool size and shape used for layup of parts. 10. Limited area for loading of parts in to the autoclave.

All the issues are analysed using quality tools and the probable solutions are listed using brain storming after interaction with the user and cross functionality team members.

2.2 REMEDIES

The probable measures taken to overcome the above issues are as follows.

1. Tool data was collected and analysed the heat up rate and cooling rate based on the thermal survey reports.
2. The tools are grouped based on the tool material type and its geometry.
3. The leading and lagging points are identified from the tool thermal survey reports to fix the thermocouples.
4. The parts are classified based on its type of resin and its set temperatures.
5. Parts are listed and classified as per their fabrication lead time.
6. Autoclave thermocouple ports are enhanced.
7. Vacuum lines are doubled using ‘T’ joint connections.
8. Multilevel loading trolleys are implemented instead of single level loading.
9. All the parts are schedule for curing considering its lead time, tool properties & cure cycle type.
10. List of schedules are displayed in advance at the layup area to follow up the layup activities.
11. Autoclaves are interconnected to a centralised server to monitor the cure process in a single station.

12. A new, more efficient layout was established to reduce travel time. Flow was redefined to meet demand, and all processes were standardized and documented.

It is found that the part heating rate depends on the thermal conductivity of tool, tool thickness, no.of layers in the part and the air heat up rate. Hence the tools with similar material and thickness are stratified and grouped together as shown in the fig.8 and a tool thermal survey was carried in an autoclave to understand the thermal behaviour of the tool and also to group the similar parts in a common vacuum bag to reduce the bagging time and cost.

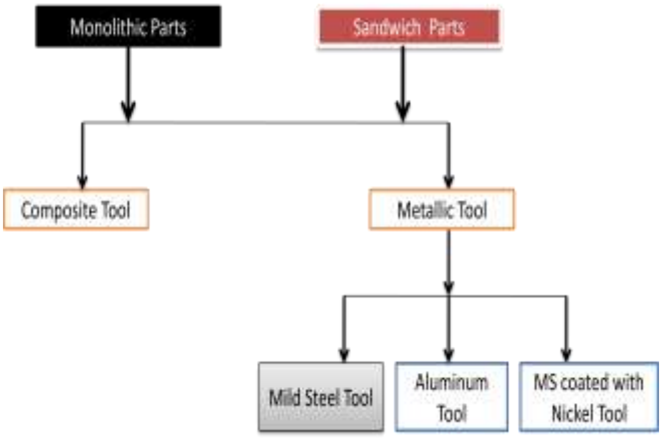

Fig.8. Grouping of tools used for fabrication of composite parts Fig. 9. Grouping of parts and bagged in a same bag.

However the degree of cure or the resin conversion rate of any epoxy resin system depends on the maximum cure temperature and time[7]. Hence the parts with a particular resin system was categorised and the lead time for fabrication of each component was analysed so as to schedule the material cutting and layup process accordingly. A new approach was created for prepreg cutting / Kit Cutting which was synchronized with the Autoclave schedule, resulting in more efficient Pull system workflow as shown in the block diagram fig. 10

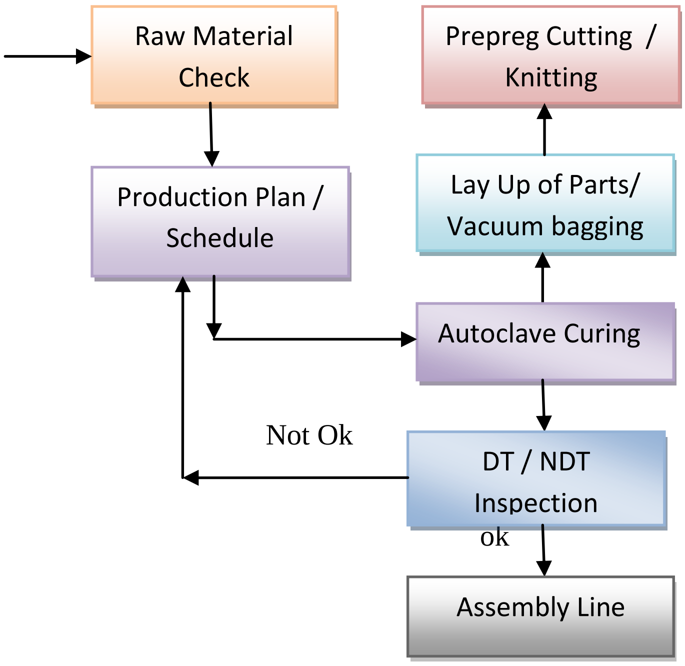

Fig.10 Pull System for manufacturing of composite parts

Autoclaves are designed with high cutting edge technologies using sophisticated controllers that are connected to a robost programmable Logic Controller (PLC) to automatically maintain a thermal uniformity of $\pm$ 5 ^{o}C throughout the length of the vessel from the door end to the fan end [8] as shown in the fig 11. since they are closed and insulated pressure vessels the air flows uniformly throughout the working diameter heating the parts loaded inside the autoclave uniformly and hence multilevel loading trolleys can be used instead of a single level loading trolley to load more number of parts in to an autoclave so as to utilize its overall working volume efficiently. Fig.12 shows a fabricated multilevel trolley used to load small components for curing. In case if one or more autoclaves are to be monitored during curing then these autoclaves can be interconnected to a common centralised system so as to monitor and control the cure process from a single point[9] as illustrated in the block diagram Fig.13 at present few researchers have made attempts to run these autoclaves through artificial neural networks or the knowledge based system to automate the autoclave operations[10].

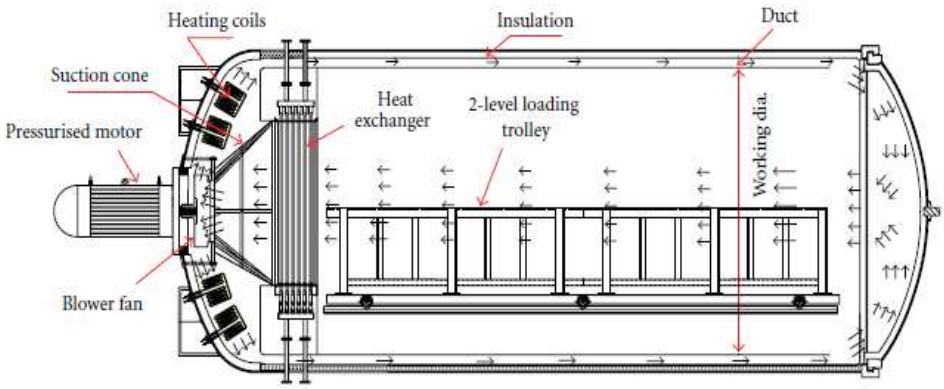

Fig.11 Air flow arrangement inside an autoclave

Fig.12 Multi Level loading trolley for loading parts

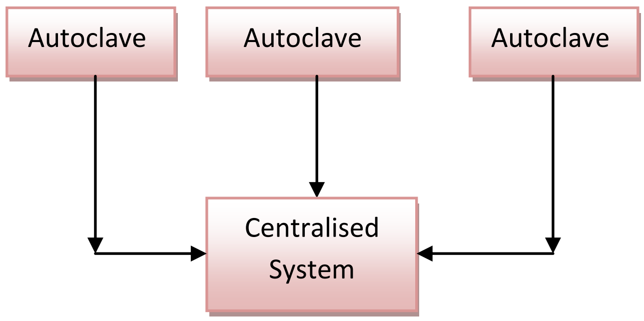

Fig.13 Autoclave connected to a centralised system

Vacuum ports are enhanced by connecting a ‘T’ slot connectors to the suction and measurement lines so as to accommodate vacuum supply for more number of components loaded in to the autoclave, at the same time the thermocouple ports are increased and the ports are provided at the door end, middle and at the fan end of the autoclave so as to connect the part thermocouples and to track the part temperatures during the curing process. Also these thermocouples are connected to the autoclave recorders and inturn interfaced to the autoclave temperature controllers to monitor the leading and lagging temperatures.

3. RESULTS AND DISCUSSIONS

Ten pilot runs were carried after implementing the pull system, and from the trial runs it was noticed that the average no. of parts cured per batch was increased from 12 parts to 26 parts as shown in the fig. 14 as a consequence the autoclave volume utilised was increased significantly from 50 % to 80 % as shown in the fig.15 with the average curing cost per part account to Rs. 1100/- with a drastic saving of Rs. 1400/- per part that accounts to reduction in curing cost per part up to 56%.

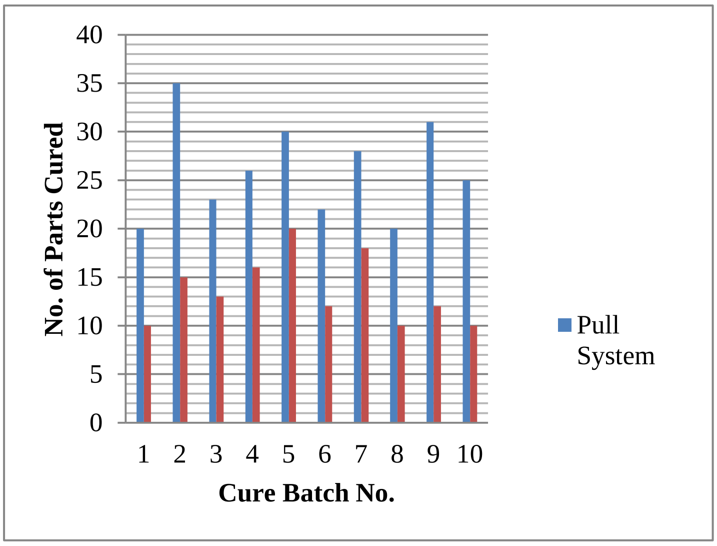

Fig.14 Number of parts cured per batch

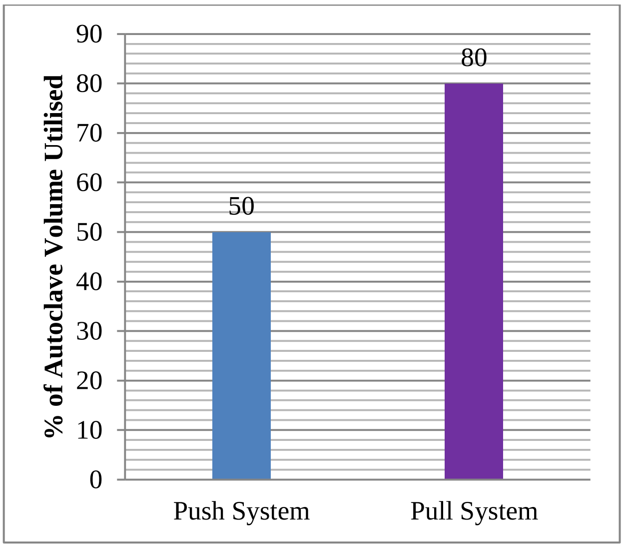

Fig.15 Percentage autoclave volume utilised

Analysis of autoclave snags and rejections was carried and found the snags rate have reduced up to 60 % and uniform heating rate was maintained during the curing process. Autoclave was scheduled in advance in line with the layup of parts which gives flexibility for planners to react to the situations and to take immediate decisions to maintain efficient work flow throughout the process. A single operator can monitor all the autoclaves situated in a composite shop efficiently through the centralized system and with close monitoring any errors during curing process can be easily traced and rejections can be avoided. All the cure charts can be printed and viewed at one station and also the cure charts can be viewed any system connected through the LAN network for quick clearance from the quality department.

4. CONCLUSIONS

A new approach for manufacturing composites to synchronize all the associated process with the autoclaves was implemented efficiently to pull the production and to enhance the autoclave utilization. This autoclave pull system proves to be effective in a composite manufacturing industry to enhance the productivity through optimum utilization of the autoclaves. This pull system result in increase of production rate by 30 % and decrease in cure cost per part up to 50% . This system can be implemented easily in any composite manufacturing industry with a minimum cost to accomplish better work flow lines and to reduce the overall production cost.

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