COST REDUCTION IN AUTOCLAVE PROCESSING I: HEATED TOOLING AND COOL AIR PRESSURISATION

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Introduction

There is increasing interest across the range of composites manufacturing processes for cost reduction with a current focus on out-of-autoclave (OOA) processes [1], especially OOA prepreg [2] and resin infusion under flexible tooling [3-5]. However, for the highest performance composites, the maximum fibre volume fraction is limited by the compressibility characteristics of the reinforcement. For any specific reinforcement, vacuum-only processes cannot achieve fibre contents as high as those where additional external pressure is applied. Compression moulding in a hydraulic press creates limited compaction perpendicular to the line of action of the press. The autoclave is good process for consolidation of complex three-dimensional components, but suffers from a number of limitations:

(a) Pre-impregnated (prepreg) reinforcements incur a high cost premium,
(b) High energy input for heating and air circulation: flow speeds in the range 1.4-2.1 m/s [6],
(c) Non-uniform heating of the components in the vessel due to turbulent flow, windward *vs* leeward location, flow stagnation and consequent temperature differences,
(d) Thermal lag due to the tool or consumables between the heat source and the composite,
(e) Long cycle times which may be a “bottleneck” constraint,
(f) The complicated heat transfer problem may require numerical models [7, 8].

The Plymouth Aeroform autoclave (Fig. 1 left) was commissioned during Summer 1989. The cylindrical working volume is 670 mm diameter by 1600 mm long with a maximum temperature of 400ºC (673K) and maximum pressure of 1380 kPa (14 bar/atmospheres). When operating with an air environment, pressure is provided by an Ingersoll Rand 3 cylinder 2 stage compressor. The autoclave could also be (re-)configured for pressurisation from liquid nitrogen cylinders. Ten 3kW electrical heating elements are positioned in an annular channel adjacent to the insulated vessel wall with the air circulation driven by a 3.5 kW fan (~34 kW system overall).

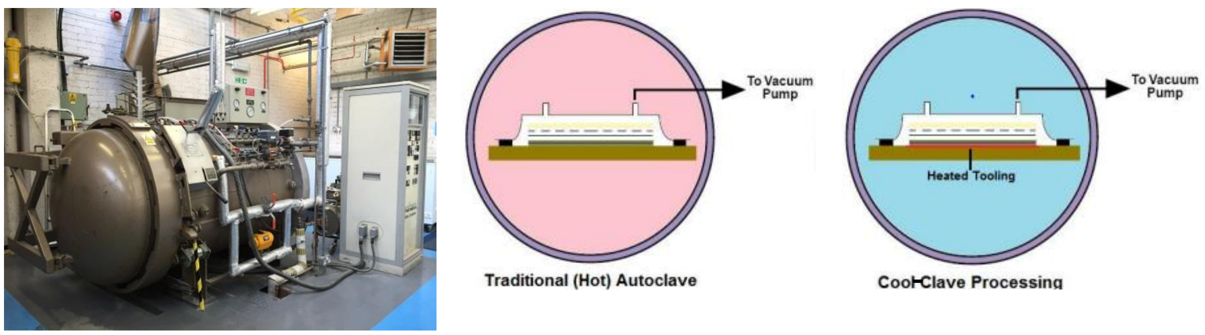

Figure 1: The Plymouth autoclave (left), schematic of conventional autoclave (centre), cool-clave (right).

Research question

In order to heat the component, it is normal to parasitically heat all the air in the pressure vessel and the thermal insulation of the vessel (Fig.1 centre). Heated tools [9, 10], with adequate thermal insulation, could be used to cure the component with minimal heating of the surrounding air and the vessel insulation. This paper considers the combination of heated tools with cool air pressurisation in the autoclave (Fig.1 right), designated as the “cool-clave”.

Methodology

The analysis which follows assumes the cure cycle for 12.7 mm thick Cytec Cycom 5216 epoxy prepreg: (a) heat from 20ºC to 80ºC, (b) pressurise to 7 bar, (c) restabilise at 80ºC, (d) hold for 30 minutes, (e) heat to 130 ºC and (f) hold for 95 minutes. The total volume of gas in the Plymouth autoclave is estimated to be 1m^3 (cylindrical working space, plus annular heating channels and domed ends). The estimated energy usage was **3620 kJ** with data for each phase presented in Table 1.

Table 1: *Estimated energy consumption of the pressurised autoclave using the Perfect Gas law and thermodynamic analysis*

Phase	*a*	*b*	*c*	*d*	*e*	*f*
Start (ºC)	20	80	28	80	80	130
End (ºC)	80	28	80	80	130	130
Energy (kJ)	158	0	1061	306	1014	1081

Three [-45/+45]$_{3s}$ Cytec Cycom 5216 560 gsm non-crimp fabric glass fibre/epoxy composites were manufactured out-of-autoclave on a heated mould tool. Laminates thicknesses were 2.46±0.06 mm, 2.47±0.06 mm and 2.72±0.06 mm, with fibre volume fractions in the range 47-53%. The energy consumption for the three laminates was 900 kJ, 936 kJ and 972 kJ respectively. Scaling from the test mould (40% of the maximum mould tool area that would fit in the autoclave) to the maximum tool size suggests an energy requirement of **2340kJ**. A single test laminate was manufactured in the autoclave using a glass plate mould. The cured composite was 2.09±0.05 mm thick, with 16.7% resin loss and a volume fraction of 62%.

Discussion and conclusions

The mould tool used was an initial prototype with considerable scope for improved performance. The estimated 35% energy saving for the cool-clave process relative to the “traditional” process does not include additional compressor energy to compensate for Charles’ Law heating and expansion of the air in the vessel. In the study reported here, the energy consumption of the compressor and control unit are considered to be unchanged between the two processes. In practice, the cool-clave will require some additional compression.

Cool air pressurisation would permit the inclusion of tools with different curing cycles in a single autoclave cycle with potential for more efficient use of the pressure vessel.

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