MICRO-STRUCTURAL ADHESION IN BIO-COMPOSITE MATERIALS DURING THEIR HEATED CONSOLIDATION

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1. INTRODUCTION

Mechanisms operative within bio-composite materails during heated consolidation interact in three space dimensions and time as their porous structure is compacted and gains structural integrity. Consequent structure-property relationships determine product performance. Mechanisms include: 1) heat and moisture transfer with phase change and within-void vapour convection and diffusion, 2) hygro-thermo-viscoelastic micro-stress accomodation and associated macro-scale densification [1,2], and 3) thermally driven adhesive polymerization and consequent inter-fibre strength development. The mechanisms' interaction has been modelled deterministically with a view to aiding in product developement and optimization [1,3]. Material property input data measurements include fluid permeability and tortuosity as functions of material compaction, and non-linear high strain viscoelasticity [4,5,6] as functions of sorbed cell wall moisture content and temperature (along with thermal conductivity and sorptive characteristics) [6]. Emphasis is given here to the role of adhesion in the process. Adhesion kinetics data have been measured with the ABES (Automated Bonding Evaluation System) technique [7], and these data have been incorporated within the simulation models to yield a 3-D mappings of micro-structural bond strength.

2. BOND STENGTH KINETICS

The rate at which adhesive micro-bonds develop strength within many types of composite material during their heated consolidation critically influences product structure and industrial manufacturing efficiency [7,8]. Matching the reactivity of adhesives to processes and material variables requires information on the responsiveness of adhesives to transient thermal, mechanical, and chemical environments. An overview of the ABES instrument employed here to measure adhesion kinetics is shown as Figure 1.

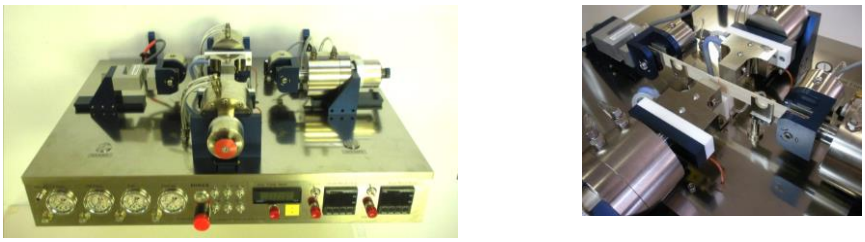

Figure 1. The Automated Bonding Evaluation System (ABES) instrument

2.1. Measurement methods and results

Miniature bonds (commercial UF adhesive with solids content of 65%, catalyzed with 1.25% NH_4Cl, applied at 45g/m^2, and 0.7mm thick maple wood, measuring 20mm x 5mm) were formed and tested in the instrument under dynamically controlled conditions of temperature, pressing load, and time. Bond lines attained target temperatures (+/- 0.8^{o}C) within 6 seconds and, having reached the pre-selected cure level, were tested within 3 seconds (4MPa/sec loading rate). The derived set of near-isothermal strength development data (Figure 3, left) exhibits nearly linear strength development up to quite high strength levels, and linear regression was applied to the early stages of cure. The slopes of the regressed lines represent the bond strength development *rates* corresponding to the pressing temperatures employed [8]. Plotting these rates against forming temperature reflects the reactivity of the adhesive-substrate combination (Figure 2, right). Rates of thermal damage (declines after peak strength attainment) have also been extracted.

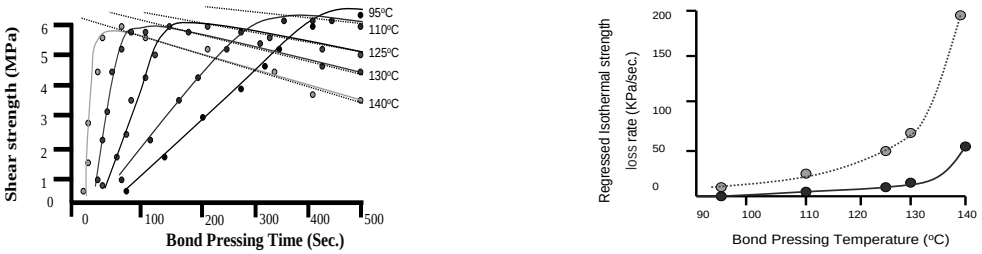

Figure 2. Isothermal strength development plots (left) and regressed rates versus temperature (right)

2.2. Modeling adhesion mappings in an industrial press

To demonstrate the significance of the measured adhesion kinetics (ABES) data, numerical methods have been used to estimate the development of bond strength that occurs in an industrial continuous press where internal temperatures change with time [9] (simulated and mill-validated MDF mat was initially at 9.6% mc, temperature of 40^{0}C, density of 100 kg/m^3, pre-compressed height of 166 mm, and width of 2.3 m; press with an in-feed radius of 30 m at a speed of 129 mm/s). The predicted cross-sectional distribution of temperature and resultant bond strength along the length of the press is shown as Figure 3. As expected, bond strengths are clearly slowest to rise in the core region of the modeled composite [6]. Surface zones do, however, show signs of decline (damage) after prolonged exposure to high platen temperatures.

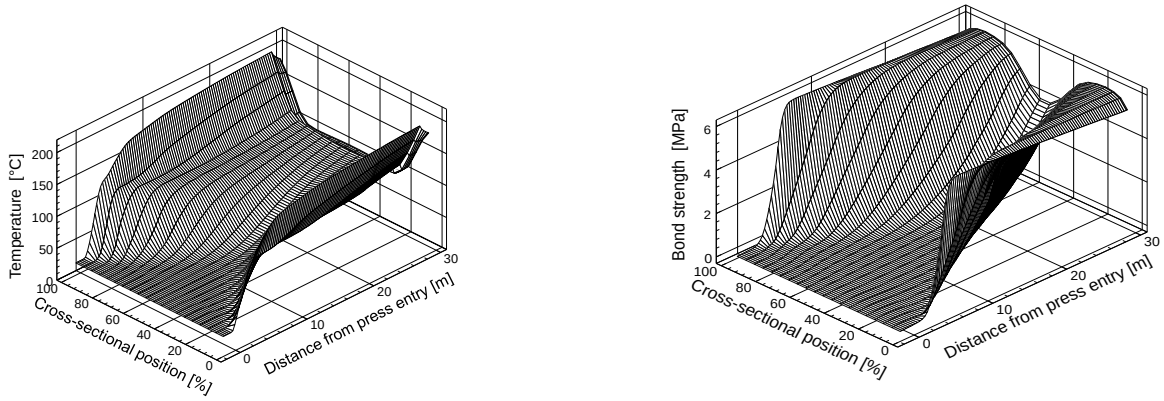

Figure 3. Cross-sectional temperature (left) and bond strength (right) mappings within the modeled industrial MDF mat

3. CONCLUSION

Adhesion kinetics of a UF adhesive has been evaluated over a temperature range of 95- to 140-^{o}C and the derived data applied to the changing conditions that occur in an industrial continuous press. Clearly, the scale and topography of the test bonds does not match the nature of bonding sites in an MDF panel. Predicted spatial mappings must therefore be interpreted with care. Such predictions are useful when evaluating and comparing the likely behaviour of a range of adhesive formulations and press operating strategies. Further, the ABES technique may be used to aid in adhesive development without applying the data to process models. Superimposed on the strength increasing data are the effects of curing temperature on bond strength maxima and the rate of post-maximum decline. The latter may be attributable to thermal damage to the polymeric structure of the cured adhesive. Strength maxima also appear to be higher when bonds are held at low and moderate temperatures for prolonged periods (rather than being cured quickly at high temperature). This effect may be due to the reported tendency for polymer chain lengthening to be greater at low temperatures (as opposed to a predominance of 3-D cross-linking which is favoured at higher temperatures [6].

References

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