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THERMO-MECHANICAL PERFORMANCE OF A NOVEL COMPOSITE LINER USED IN CURED-IN-PLACE PIPE RENOVATION PROCESS

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Abstract: This paper aims to describe the latest developments in the cured-in-place lining process and present the results of an investigation into the thermo-mechanical properties of a novel composite material used in the process of cured-in-place pipe renovation. The results include the effect of catalyst content on the dynamic mechanical and thermal properties of the felt liner polyester composites. In this study a novel type of pipe liner was prepared using a special felt- polyester material. It has been found that when the felt material is incorporated in the resin the flexural modulus is reduced by 6%. It has been established that the use of 1.8% catalyst in the resin results in the highest flexural modulus of 2.6 GPa.

1. Introduction:

Cured-in-place pipe (CIPP) sewer line repair is a complex process that requires a clear understanding of the different chemical and physical parameters involved. In this process a felt liner is impregnated with polyester resin and then it is cured in place to cover the damaged area of the pipe from inside. Once a sewage bypass has been established, there are generally two ways to approach repairs. One is to build a hydrostatic head and invert the impregnated liner in the host pipe by using a pressurized column of water. Another way is to pull the liner through the pipe and then run a small calibration hose through the liner. The hose inflates the liner using pressurized cold water until it fits snugly against the host pipe. Once the bag is inflated, the water is re-circulated by pumping the water out of the liner and through a boiler. Pressure is maintained to ensure the liner stays "inflated" against the walls of the damaged pipe while the water temperature rises to begin curing the resin. After the recommended curing temperature is reached, it is held for two hours or longer and then a controlled cool down is accomplished. The cool down time is generally three hours or longer. The liner is designed to be a stand alone structure, even if the host pipe totally deteriorates, the cured liner alone can hold all the load of the soil and the hydraulic forces that are present. The quality of the resin is what will enable a liner to withstand the hydrogen sulphide environment and the physical pressures. It is therefore important to optimise the gel and cure process to enable the designer to predict the long-term performance of the cured liner. Hence it is vital to know the optimum amount of catalyst in the impregnated felt liner, which leads to the best flexural modulus and tensile strength of the cured liner. Also the resin is required to remain stable after it is catalyzed for about 3 hours from wet-out until the bag is inserted in the line. Curing is effected by use of an organic peroxide initiator which generates free radicals leading to the formation of a three-dimensional network. Polyester resins are relatively inexpensive and have low

viscosities, which is beneficial in many fabrication processes. However, the shrinkage, which occurs on curing, is high (4-8%). Polyester resins such as these are of the 'unsaturated' type. Unsaturated polyester resin is capable of being cured from a liquid or solid state when subject to the right conditions. It is usual to refer to unsaturated polyester resins as 'polyester resins', or simply as 'polyesters'. There is a whole range of polyesters made from different acids, glycols and monomers, all having varying properties.
There are two principle types of polyester resin used as standard laminating systems in the composites industry. Orthophthalic polyester resin is the standard economic resin used by many industries. Isophthalic /DCPD (pre-filled) version of Gadres 4000 resin is now becoming the preferred material in pipeline renovation and marine industries where its superior water resistance is desirable. The cross linking reaction is initiated by molecules that readily produces free radicals (a chemical species with an unpaired electron). The most common group of molecules which produces these free radicals are the organic peroxides. The rate of free radical production is highly temperature dependent, therefore, producing the free radicals which are initiating the cross linking reaction can be accelerated by increasing the temperature (Zorgani-Errajhi, 2005).
Rueggeberg and Craig used the surface hardness for measuring the degree of polymerization, which plays an important role in determining the material durability. Surface hardness testing has been used in many studies due to its relative simplicity and good correlation to the degree of conversion using infrared spectroscopy (Rueggeberg and Craig 1988). Watts and Grant have reported that micro hardness testing can be performed to evaluate the setting reaction of the light cured resin composite. The increase in micro hardness levels indicates the resin setting reaction continues after light curing. This increase is an indicator of the maturity of the reaction or its stage (Watts et. al, 1986). Baiyndir and Yildiz (2004) used the hardness testing to evaluate the curing performance of composite materials used in water storage. Nilgun et al. (2005) evaluated the degree of conversion and Vickers surface hardness of resin cement under a simulated ceramic restoration with 3 different curing units: a conventional halogen unit, a high-intensity halogen unit, and a light-emitting diode system. Mandikos et al (2001) used Vickers hardness to test composite materials. The Pearson correlation coefficient was used to determine the existence of a relationship between the hardness of the materials and the degree to which they had worn. The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces have been used to test A shaft made from carbon fibres and resin (Globalspec, 2007). The flexure test method has been applied to measure behaviour of materials and to determine flexural properties of composites in the form of rectangular bars, subjected to simple beam loading (Razmara and Saidpour 2004), (Rodd, 2005). De Albuquerque and Joseph (2000) have investigated the flexural behaviour of reinforced polyester composites as a function of fibre loading and fibre surface wettability. Parodi Parodi (1999) used a flexural test according to ASTM D790 to compare the properties of unsaturated polyester, vinyl-ester resins and their composites. Also static flexural test is used to measure the flexural properties of straw-reinforced polyester composites (White and Ansell 1983). Dhami

and Bahl (1997) determined the flexural strength and flexural modulus of the unidirectional composites using the three point bending method. The effects of the volume fraction and length of natural fibres on flexural properties of biodegradable composites have been investigated by Shibata and Cao (2005). Hazizan and Cantwell (2002) conducted an investigation on the rate sensitivity of the glass fibre reinforced polymers by performing three point bend tests. While flexural testing measures the elastic modulus, DMA would give the storage modulus, E' of polymers. The storage modulus can be thought of as the stiffness of the polymer, like flexural or tensile modulus (Griffin, 2005). DMA can be simply described as applying an oscillating force to a sample and analyzing the material response to that force (Menrad, 1999). DMA has been used to study the dynamic mechanical thermal properties of unsaturated polyester resins (cured) and composites of unmodified and chemically modified jute-polyester over a wide temperature range by Saha et al (1999). Taheri and Mohammadi (2005) used DMA technique to study the effects of styrene content in unsaturated polyester resin, their results show that the styrene content enhances the crosslink density of the networks. This alters the intensity and broadness of α relaxation. Also the effect of styrene content on the performance of unsaturated polyester resin has been investigated using other thermo-mechanical techniques including mechanical spectroscopy, DMA and TSR (Mano and Saiter 2005). Aziz and Ansell (2005) used DMA test on modified unsaturated polyester resin composites and found that the modified composites yielded the highest storage modulus (E′) values and the lowest tan δ values. Alves and Mano (2001) studied the conformational mobility of a polyester thermoset in the glass transition region using DMA in the flexural mode.

2. Experimental details:

Two different methods, namely flexural and DMA, were used to assess the thermo-mechanical performance of the composite liner samples. The different samples used for flexural and DMA tests were prepared using a special felt material (Gadliner) and neat polyester resin (Gadres 4000), supplied by Gadmon Industries (UK). Gadliner is a non woven low stiffness felt tube, coated with a plastic PVC film, for commercial reasons it is not possible to disclose any further details .The felt- polyester composites were prepared using different amount of Dibenzoyl peroxide catalyst according to established standards (ASTM 1986), (ISO 1993). All samples were cured at the ambient temperature for 24 hours followed by a post cure regime of 2 hours at 40 ^{o}C.

The catalyst used works as a free radical initiator rather than as a catalyst in the usual sense meant by chemists. They are not true catalyst as they are consumed in the reaction (Rodd 2005). Changes to the amount of catalyst may cause different effects on composites, higher amounts of catalyst may speed up the rate of cure which could potentially increase the adverse effects of reducing modulus due to the non-active 'carrier ' in the catalyst (Matthews and Rawli 1994) (Rodd 2005).

To establish the best resin catalyst formulation, various amounts of catalyst (1.8 to 4%) were added to the resin-felt system before testing the samples using flexural and DMA methods. The test rigs used to carry out the tests include, Instron 1026 testing machine for 3 point flexural testing, and DMA 242C for dynamic mechanical thermal analysis.

3. Results and discussion:

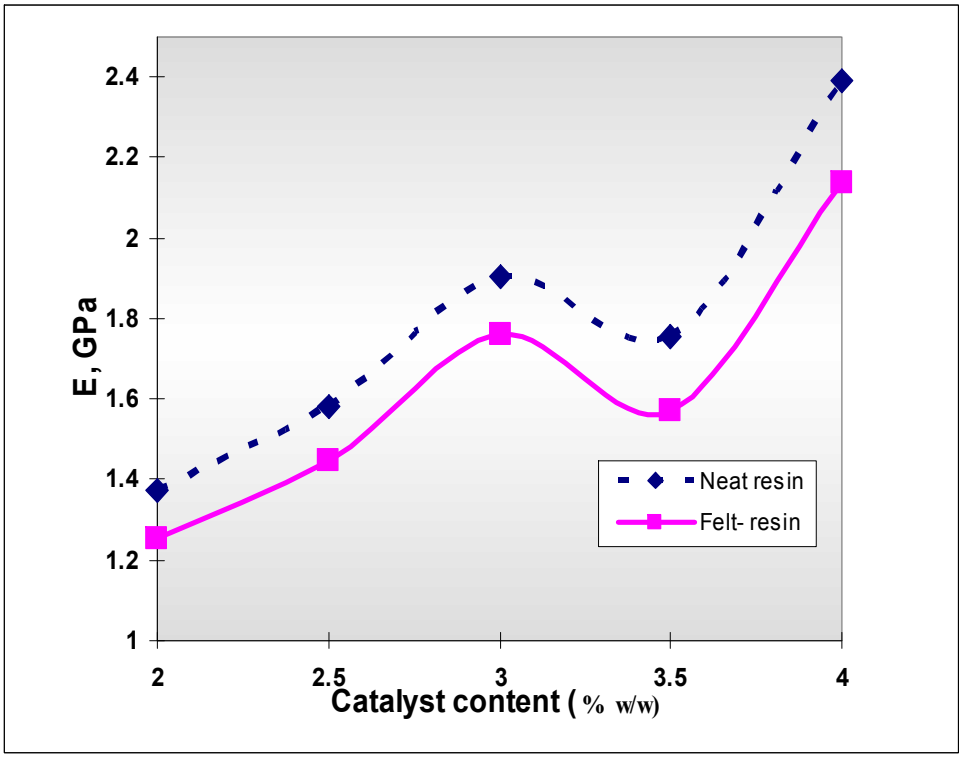

Figure 1: Flexural modulus (GPa) vs. Catalyst content (% w/w)

The results of the flexural test on different samples including neat resin and felt-resin composites with different amount of catalyst are presented in Figures 1. It can be observed that the modulus increases to a peak value at 3% w/w catalyst which subsequently drops to a minimum value at 3.5% w/w catalyst before rising to another high value of 2.0 GPa for resin-felt composites and 2.4 GPa for neat resin samples at 4% w/w. Kin-tak et al (2006) have reported that, the cause for reduction in the mechanical properties may be due to the structural non-homogeneity and/or existence of a weak-bonding interface between the felt and the matrix, as observed in 3.5% w/w catalyst samples.

Contrary to the decreasing trend in modulus values when incorporating felt, significant improvements in the strength values have been observed in felt-resin composite samples. Figure 2 shows that using felt in the composite increases the strength by 1.8% at 2% w/w catalyst. However, it can be seen that after 3% w/w catalyst the strength values of both neat resin and felt-resin composites are very similar. Although using 4% w/w catalyst results in an improved modulus and strength properties but the short period of "working open time" limits the usefulness of this formulation. It can be concluded that 3% catalyst formulation leads to the most optimum properties for the present CIPP system used in this study.

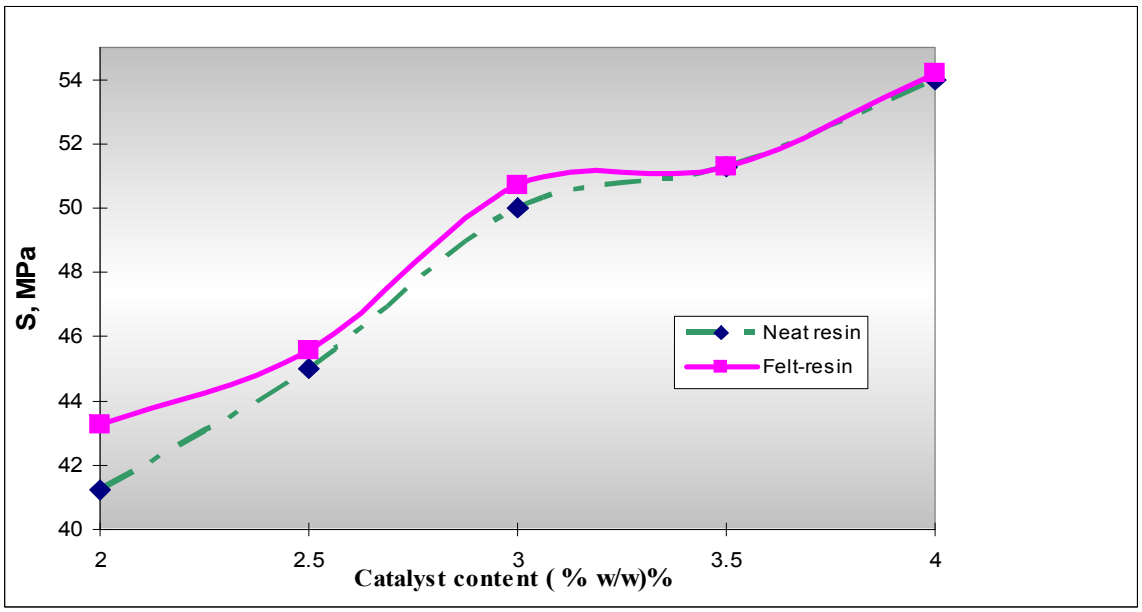

Figure 2 Flexural strength (MPa) vs. catalyst content (% w/w)

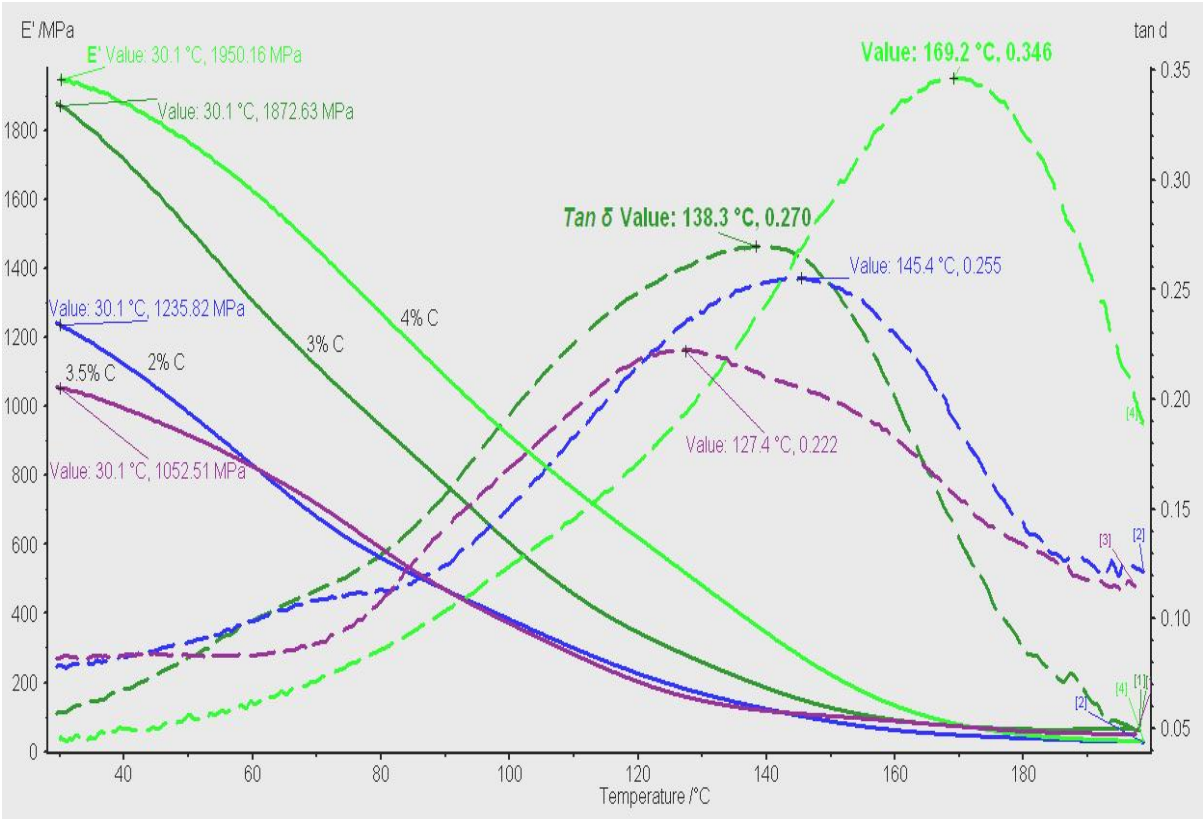

Figure 3: DMA test results of neat resin samples in DCB mode

The comparative results of DMA tests on the different samples with varying amounts of catalysts in dual cantilever bend (DCB) and three-point bend (3PB) modes are shown in Figures 3 and 4 respectively. It has been observed that at 30 °C, the E' value for 4% catalyst sample (1950 MPa) is marginally higher than that of 3% catalyst samples. The selection of optimum catalyst amount is normally dictated by the E' values. The DMA results indicate that E' value for 3% catalyst samples at ambient temperature is considerably higher than that of 2% and 3.5% catalyst samples. Although 4% catalyst samples lead to higher E' results, however due to the much lower gelation time this formulation is unsuitable for CIPP applications. Therefore it is more appropriate to choose 3% catalyst as the optimum catalyst content due to higher working time of resin.

Furthermore tan δ profiles shown in Figure 4 provide useful information on the best selection of the resin-catalyst formulation. Tan δ values give an indication of relative material toughness (Knappe 2005). It can be seen that 2% and 4% catalyst formulations results in the lowest and highest tan δ peak respectively. This indicates that 4% catalyst leads to the best resin performance, however this is unsuitable due to a short working time. Hence 3% formulation possesses the next highest tan δ value. Similar trends in tan δ and E' values can be observed by referring to DCB profile in Figure 3.

Furthermore tan δ profiles shown in Figure 4 provide useful information on the best selection of resin-catalyst formulation. Tan δ values give an indication of relative material toughness (Knappe 2005). It can be seen that 2% and 4% catalyst formulations results in the lowest and highest tan δ peak respectively.

Consideration of the glass transition temperature (Tg) for the different samples can potentially provide further insight into the degree of cure and crosslinking of the different samples used (Figure 5) In this study glass transition temperature was taken as the temperature at tan δ peak. It can be seen that when 3.5% catalyst is used the composites have the highest Tg. This corresponds with the high cross linking of the resin matrix. However this formulation results in much lower E' values at ambient temperature, therefore cannot be short listed for the best formulation.

4. Conclusions:

- The flexural and dynamic-mechanical behaviour of Gadres resin with and without felt liner have been studied in an attempt to establish the optimum resin-catalyst formulation.
- The flexural modulus and strength increased when the catalyst loading increased from 2 to 4% w/w.
- Using Gadliner with the resin results in a decrease of 6% in flexural modulus. Also, the flexural strength increased with increasing catalyst amount, however, using 1.8% catalyst (the lowest amount used) leads to a relatively good flexural modulus.
- The optimum proportion of catalyst was found to be 3%, considering the processing constraints including vitrification and working time.

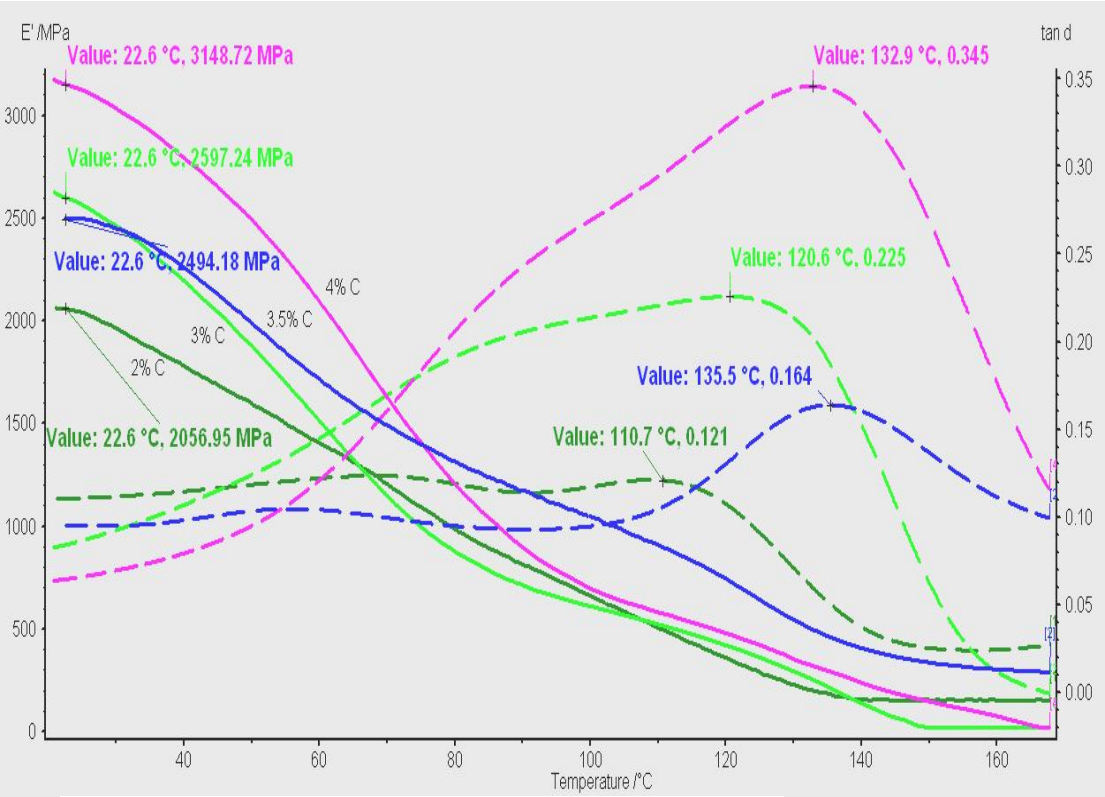

Figure 4: DMA results of neat resin samples in 3PB mode

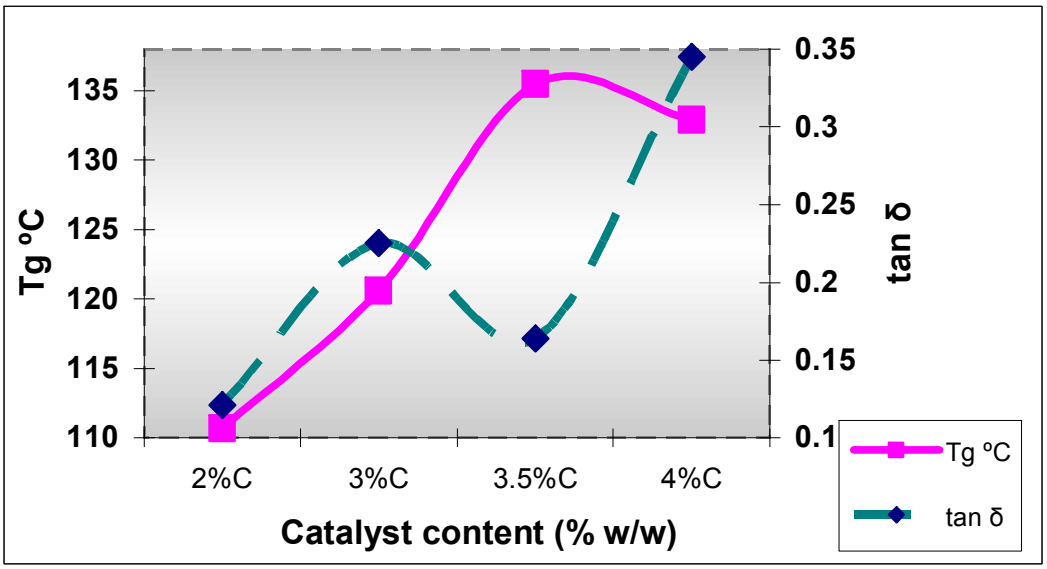

Figure 5: Tg and tan δ versus different catalyst content in neat resin samples

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