

Roll forming and the Mechanical Properties of Coil Coatings

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Introduction

Materials Science is that amorphous academic discipline that occupies the space between Chemistry and Physics. An important branch of this subject is Mechanical Properties. It covers the phenomena of stiffness, brittleness and ductility, all of which can be quantified by modulus, yield-stress, break-stress and elongation at break. Metals such as steel are stiff (high modulus), ductile (high elongation) and strong (high break stress), the values of these properties vary little over a range of temperatures from below ambient to above 300°C. In the field of coil coating continuous strips of metal are coated in a factory before being transported to a fabricator where the metal is formed. One of the most common operations is roll forming. The coatings are applied to improve the aesthetic appeal and to boost corrosion resistance. Thus they need to be durable, corrosion resistant, abrasion resistant and formable. Beckers is the pre-eminent supplier of this type of coating in Europe.

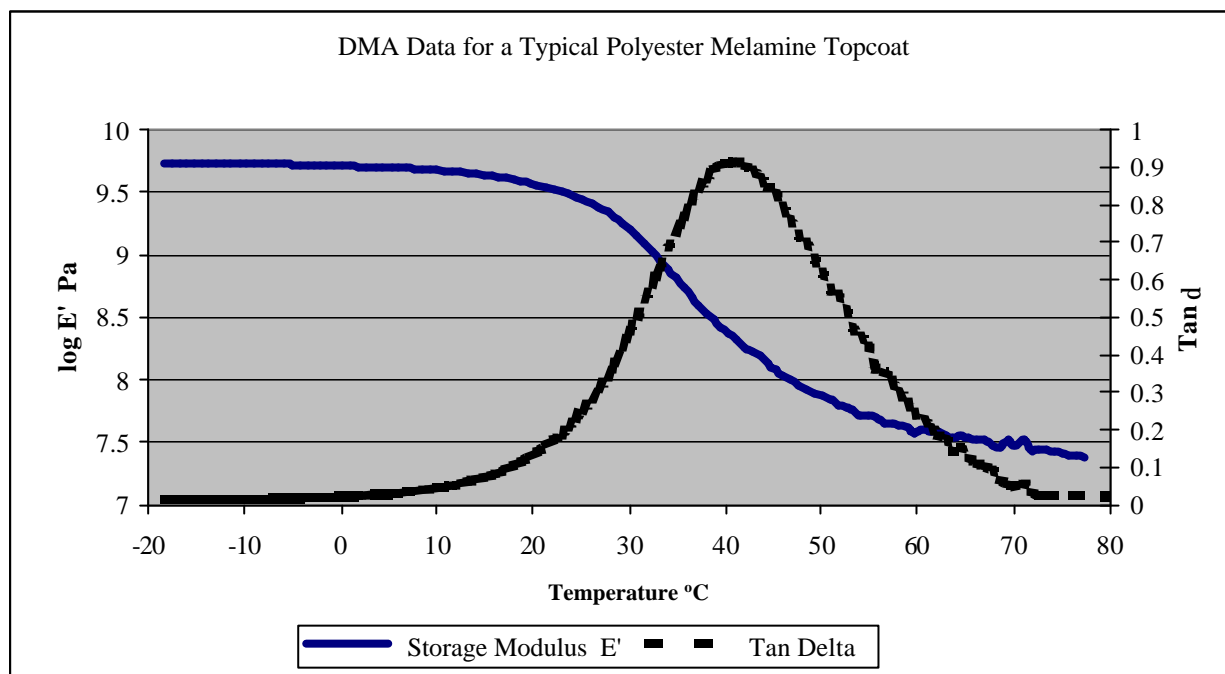
Glass Transition and All That

Polymers, under which classification organic coatings can be included, are much weaker materials than metals and in addition most have mechanical properties that can vary considerably over the ambient temperature range (-40°C to +100°C). The greatest change observed occurs within a narrow band of temperatures, the mid-point of which is defined as the glass transition temperature T_g . As the name suggests the polymer changes from a hard, glassy, brittle type of material into a more compliant material. The temperature range over which this metamorphosis takes place is governed predominantly by the backbone structure of the polymer. A high aromatic content results in a high T_g , whilst a high aliphatic content dictates a low T_g . In thermosetting systems the exact T_g attained will depend upon the degree of cure achieved, a 20°C difference between uncured and cured is typical. The crosslink density is determined by the number of reactive groups per molecule, a high number resulting in a high crosslink density and thereby short chains between crosslinks and vice versa. The rubbery storage modulus E'_R (the modulus of a crosslinked polymer at a temperature above its T_g) gives a direct measure of the crosslink density. E'_R is very similar to the Young's Modulus of the system in its rubbery state.

Dynamic Mechanical Analysis (DMA) is a technique in which a sinusoidal stress is applied to a coating and the strain is measured along with any phase difference δ) between the application of the stress and the reaction of the strain. Modulus values calculated from the raw data can be used to obtain information on T_g as the modulus drops by a factor of 100 between glassy and rubbery states (Figure 1). The peak of the $\tan \delta$ curve is more commonly used to define T_g . The added benefit of DMA is that it can be used to obtain information on crosslink density as it measures E'_R . It will also present

data from which an impression of the viscoelasticity (see later) of a material can be gleaned.

Figure 1



Mechanical Properties of Coatings (To Yield or not to Yield – That is the Question)

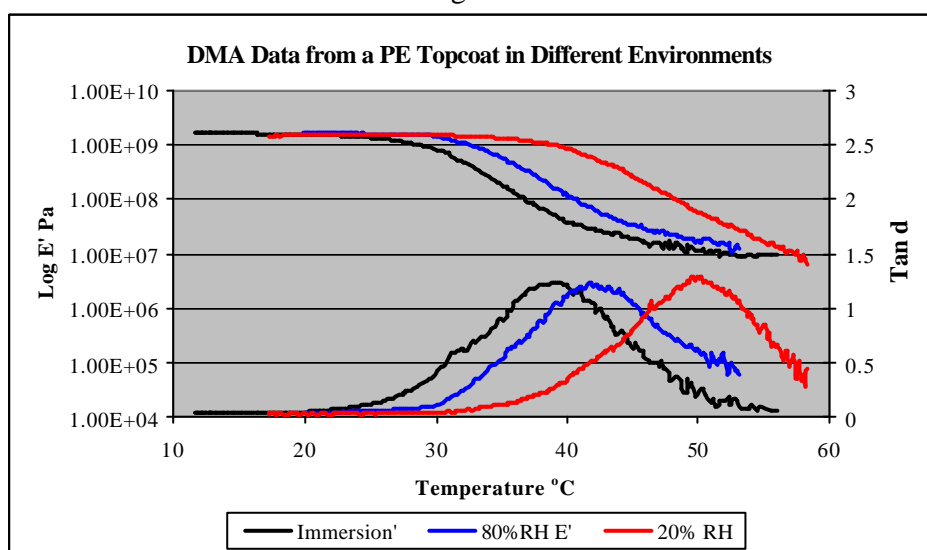
If an organic coating is to perform well as a coil coating it must have certain characteristics. It must be able to yield when the metal is bent but have sufficient strength not to break (crack) during and after the process. This is normally defined as “flexibility” but should more correctly be baptised as “yieldability”. The coating must not be elastic because the stresses built up within such a coating, when it is bent, can only be released by delamination or cracking. A recent paper described the parameters required for good formability⁽¹⁾, it formalised what has been known informally for a considerable period of time. That is; high molecular weight, low crosslink density and low Tg, are prerequisites for good formability. Thus most coil coating topcoats have Tg's between 15-35°C and an E'_R of ~10⁷, however better hardness and scratch resistance can be achieved by using high Tg, low crosslink density (E'_R ~10^{6.5}) polyester/melamine systems. These are typically used for DA systems but they cannot be aimed for exterior use due to a lack of good weatherability.

Coatings that yield at temperatures well below their glass transition temperatures reveal a paradox within polymer nomenclature, that is, how can a glassy material avoid being brittle? The general consensus of opinion leans towards the concept of brittle/tough transitions and the temperatures at which they occur (T_B). These phenomena have been observed in thermoplastic polymers such as polycarbonate in which the brittle transition

occurs 350°C lower than the T_g of 150°C. Polystyrene on the other hand has a T_g of 100°C and a T_B of 90°C. Information on the brittle/tough transitions of polyester melamine coatings, the predominant product within the coil coating industry, is almost non-existent. Beckers are working with the University of Exeter in order address this paucity of data.

Evaluation of simple brittle/tough transitions is not the only objective of the project undertaken by the University of Exeter. The effects of humidity on the T_g of polymers has long been anecdotally reported. With equipment designed and built within the University Laboratories, quantitative measurements on the effects of humidity are being made on free films tested within the sample compartment of a Dynamic Mechanical Analyser, the environment of which can be closely controlled²). Figure 2 demonstrates how humidity and finally water plasticise the film so that there is a 15°C drop in T_g between measuring in a relatively dry atmosphere (20% RH) and measuring when immersed in water. This phenomenon will have repercussions on the performance of a coating during roll forming and once in service. Humidity may also have an effect on T_B and in which case it will be possible to determine the conditions under which roll forming would be most efficiently carried out.

Figure 2



How Theory Affects the Real World

A recent case study involved a polyester melamine coating applied to thick substrate. The thickness of the substrate dictated that oven dwell times were extended. Differential Scanning Calorimetry* (DSC) results indicated that the T_g of the line run was 34°C whereas normally cured material had a T_g of 26°C. DMA results revealed that the extended cure times produced a 40% increase in E'_R and hence crosslink density. The results of creep tests are shown in Table 1. They clearly demonstrate how over-curing affects the mechanical properties of thermosets and that warm forming could alleviate

*DSC is another method by which T_gs can be evaluated and although not as sensitive as DMA it is far more prevalent due to its ease of use.

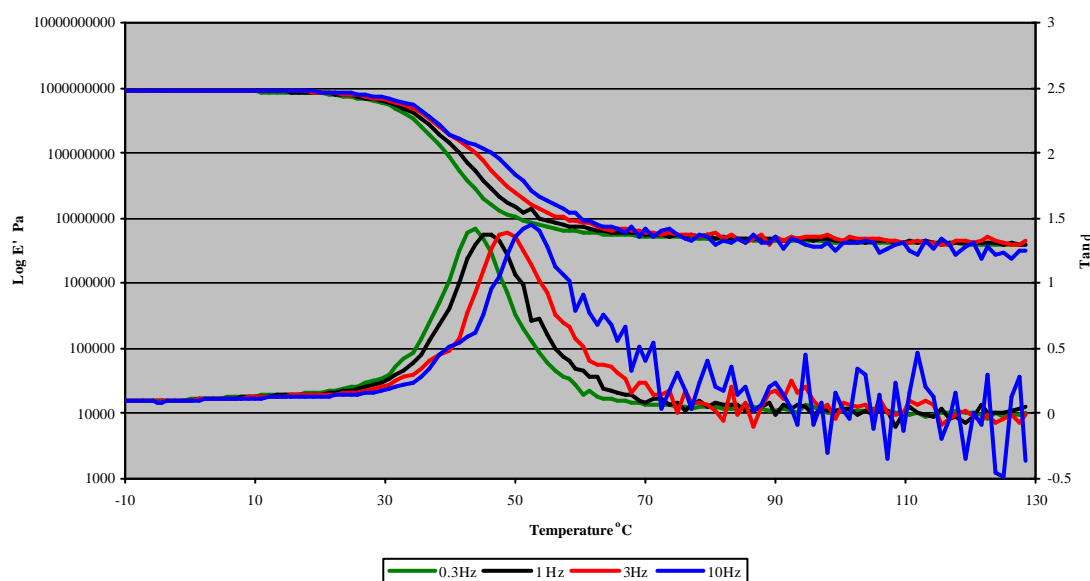
TABLE 1

| Sample | T _g | Temperature of Test | Elongation at Break | % Elongation |
|------------------|----------------|---------------------|---------------------|--------------|
| Properly Cured | 26°C | 17°C | 1500μm | 10 |
| " | 26°C | 22°C | Did not break | >55 |
| Overcured Sample | 34°C | 17°C | 664μm | 4.4 |
| " | 34°C | 22°C | 900μm | 6 |
| " | 34°C | 27°C | Did not break | >50 |

some of the difficulties encountered. It would appear from these results that the T_B is some 10°C lower than the mid-point of the glass transition range, around the same point as the onset but this needs to be confirmed.

Figure 3

DMA of PE Topcoat at Different Frequencies



Beckers has also worked with Triton Technology⁽³⁾, in order to study how changing the rate of applied stress alters the properties of a material. At this point it is convenient to describe more fully the concept of viscoelasticity. In essence the term defines how a material responds gradually to an applied stress reaching an ultimate value after a time lag. The phenomenon is caused by the chains of molecules within a polymer requiring time to fully adjust to the applied stress. Thus the more rapidly a stress is applied the shorter the time available for the molecules to relax and accommodate that stress, this results in an increase in the glass transition temperature of the polymer when it is

subjected to rapid forming. Figure 3 demonstrates that an increase in the frequency of the sinusoidal force applied during a DMA experiment from 0.3Hz to 10Hz causes an increase of 8°C in the Tg indicated by the peak of the $\tan \delta$ curve. It is clear that when rapid forming takes place in time scales of 10^{-4} s then the Tg could rise considerably. This could explain problems experienced when high speed slitting and stamping operations are carried out. The easy solution of adding plasticiser may not be that efficacious as a low Tg in service can give rise to poor stain resistance and dirt pick up.

Conclusion

Some of the science and technology behind current coil coatings has been described and the effects of humidity and rate of forming on the performance of such systems have been quantified. Beckers are continuing to discover more about how external environments affect the performance of their coatings once applied, cured and delivered to the end user.

References

- 1) K. Ueda, H. Kanai and T. Amari, Proc. 27th Athens Conf. Coat. Sci., 331, 2001
- 2) S. Ritchie, G. Foster and C. Lowe, Submitted to Thermochemica Acta for publication in 2003.
- 3) Triton Technology Limited, www.triton-technology.co.uk, Manufacturer of DMA Instruments