Rheological Challenges in Automotive Production

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ABSTRACT

Automotive production is a complex cost-intensive process that is continuously haunted by measures to reduce both production cost and time while striving after improved product quality. One way to meet such objectives is to deal with salient rheological challenges in automotive production. For an outsider it is not obvious how rheology is related to automotive production. Therefore, a brief overview will be given of a typical automotive production process with emphasis on rheology. This will be followed by a few rheological case studies related to body-in-white production.

INTRODUCTION

Automotive production can be divided into several steps. Typically, sheet metal coils coated with corrosion protection oil arrive at the press shop where additional stamping oils can be applied prior to parts stamping. Oil rheology plays a role during coil transportation, oil application, stamping as well as during subsequent parts storage, transportation and application of polymeric materials such as adhesives and seam sealants. Some pressed parts are then sub assembled as closure panels such as doors, hoods and trunk lids. Closure panels are generally adhesively bonded with hem flange adhesives. Moreover, polymeric noise-vibration-harshness (NVH) and antiflutter materials are applied. The rheological properties of these polymeric materials determine ease of application, assembly and final product performance. Other pressed parts enter the main production line at the body shop. In the body shop, sheet metal parts are joined by various joining techniques such as resistance spot welding, laser welding, metal arc welding, clinching, riveting and structural adhesive bonding. The latter is generally combined with resistance spot welding and thus referred to as weld bonding. Weld sealants are used for ensuring water tightness, and are applied to flanges prior to spot welding. Antiflutter adhesives ensure proper NVH behaviour of large sheet metal panels such as the roof. As in the case of closure panels, the rheological properties of these polymeric materials determine not only ease of application but also final car body performance.

After the body shop the car bodies are conveyed to the next production step – the paint shop. During transportation all adhesives and sealants are still uncured, and the rheology must be such that no running, sagging or dripping occurs. In the paint shop, surface oils on the car body are removed by high-pressure degreasing at 55°C, followed by a zinc-phosphate metal pre-treatment. Successful degreasing requires that the rheological properties of all polymeric materials are such that surface oils are removed but not adhesives, sealants and antiflutter materials. After metal pre-treatment, the car bodies are cathodically charged at a few hundred Volts while passing through a bath consisting of an aqueous emulsion of coating material. Electro coating is then followed by a passage through a hot-air convection oven for about 30min at 180°C. The primary function of this oven is to cure the electrocoat which is required for proper adhesion and corrosion performance of subsequent paint systems. The secondary function is to cure all heat-curable adhesives and sealants. Clearly, unfavourable rheological properties during heat-curing can affect final product performance. After curing and cooling to room temperature, the car bodies are ready for application of NVH material, weld seam sealants, roof ditch sealant and masking of window flanges. Curing of these materials takes place in a hot-air convection oven at about 140°C. An understanding of the viscoelastic properties of these materials ensures both efficient production application and proper final product performance.

The car body is now ready for the first paint layer called the primer surfacer that is cured at about 150°C in a hot-air convection oven. This is then followed by application of a top coat, and, for metallics, a further layer of clear coat. The top coat and clear coat are cured at about 140°C in a hot-air convection oven. Obviously, spray application of paint involves a great deal of rheology, too.

The next production step is the final assembly of the car. This involves joining the painted car body with the car chassis at the "marriage point", mounting all closures, windscreens, exterior and interior parts prior to leaving the assembly shop for delivery to customers. In the assembly shop, rheology plays an important role in, for instance, windscreen bonding and in taping of exterior decorative panels.

RHEOLOGICAL CHALLENGES

As described in the introduction, there are a number of rheological challenges in automotive production. Some rheological case studies related to body-in-white production follow.

Oil Rheology

As shown in Figure 1 the temperature dependence of the viscosity of some typical production oils can vary significantly. Although the amount of applied oil is as low as about 2g/m², oils with too low viscosities can result in running and thus uneven and locally reduced corrosion protection during coil and parts transportation. Another effect can be unwanted local accumulation in flanges with subsequent adhesive or sealant application. Adhesive and sealant beads can slide and be misplaced in the flanges. The oil accumulation can exceed the maximum amount of oil that the adhesive or sealant can absorb prior to jeopardizing adhesion and subsequent bond line properties. The latter also applies to oils with too high viscosities.

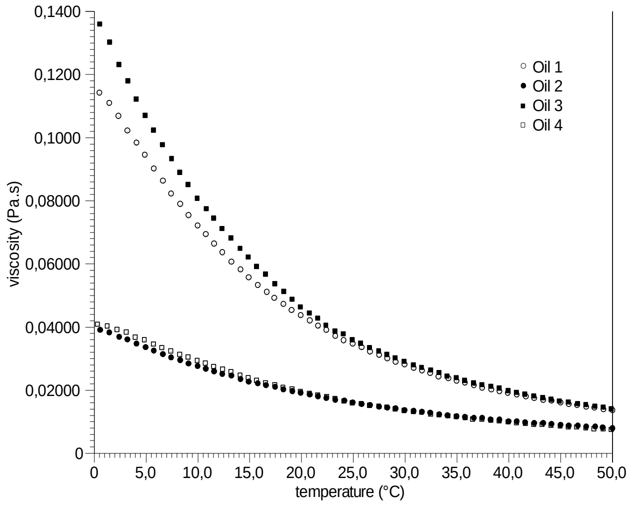

Figure 1: Temperature dependent viscosity of different stamping oils.

High-pressure Degreasing and Wash-off

During high-pressure degreasing at 55°C, all uncured viscoelastic polymeric materials in the car body are subjected to high shear and normal forces that can result in the material being washed-off the car body. The washed-off material droplets can then congest bath filters, and even worse redeposit on visual surfaces that require manual repairing after electro coating. An adhesively bonded sheet metal flange with indications of wash-off is shown in Figure 2. One way of avoiding wash-off of adhesives and weld sealants is to study some of the rheological mechanisms that control the onset of deformation and droplet formation[1].

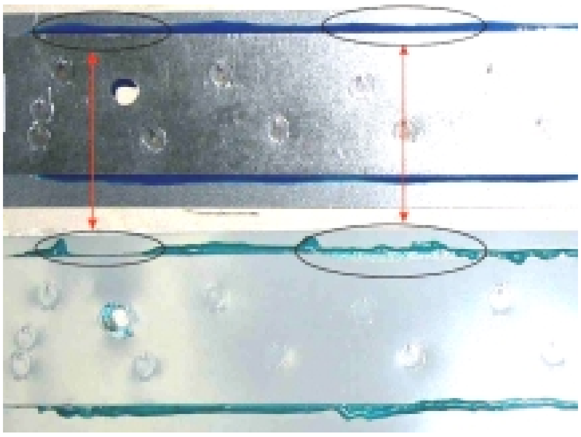

Figure 2: Bonded sheet metal flanges with adhesive wash-off indicated.

As shown in Figure 3, the complex modulus and viscosity appear to define a wash-off window where no wash-off occurs. This was found to agree with results from process wash-off tests as long as the materials have similar extensional properties. Characterization of the materials extensional rheological properties is subject to further investigations.

Heat and Adhesive Rheology

Most adhesives and weld sealants are one-component heat-curing polymer systems. Heat is used to polymerize and cross-link the materials. This often implies that polymerization will take place already at room temperature. Although the rate of reaction will be low, the rheological properties can increase sufficiently to render the material useless for robot application and subsequent joint assembly within as little as three months as shown in Figure 4. More commonly, however, sufficiently fast rates of reaction are required during oven curing in order to avoid prolonged dips in the viscosity. A typical curing profile is shown in Figure 5. Prolonged low viscosities can result in running, sagging or dripping of the adhesives and sealants in the curing oven. This can imply contamination of other car body surfaces as well as impaired product performance.

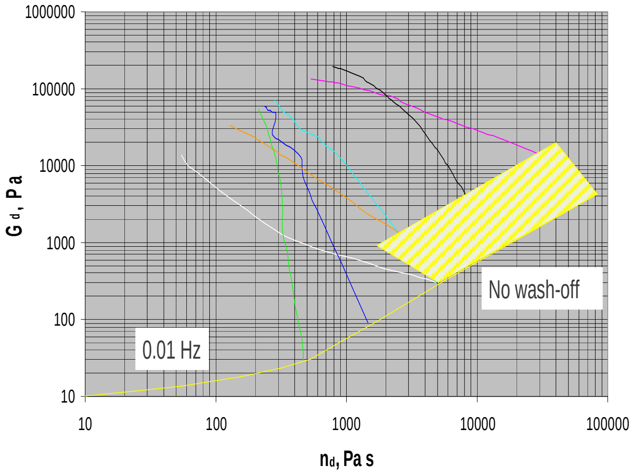

Figure 3: Rheologically defined wash-off window.

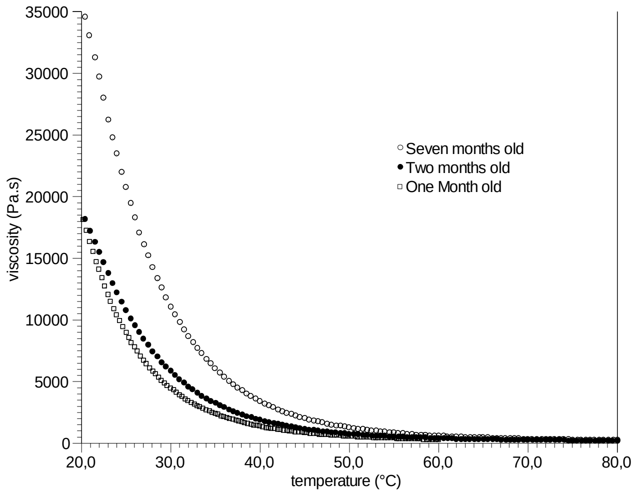

Figure 4: Effect of storage time at about 23°C on the temperature dependent viscosity of an epoxy structural adhesive.

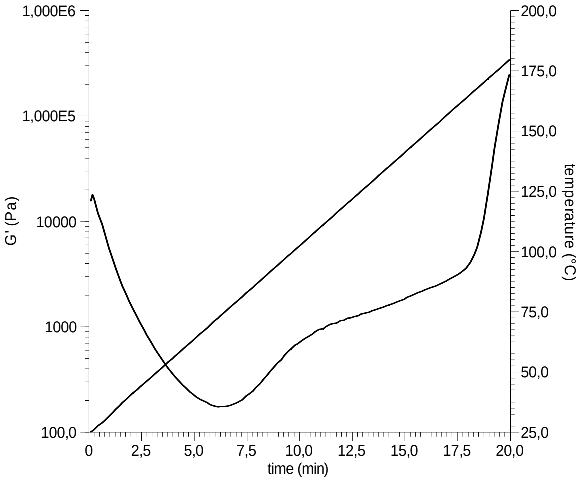

Figure 5: Typical curing profile of an adhesive.

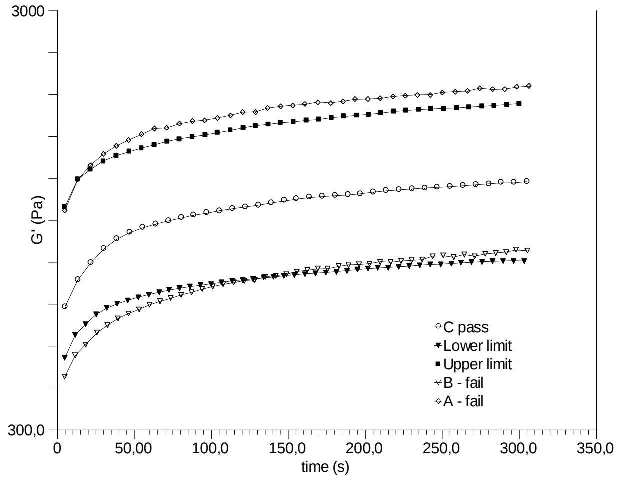

Figure 6: Typical lower and upper specifications of G' as a function of structure-build-up time for batch control of seam sealants.

<u>Seam Sealants</u>

The primary function of seam sealants is to ensure water tightness of specific flanges. Therefore, the material must remain in place after application until it is heat cured. Moreover, dripping seam sealants contaminate production floors and often require manual reworking. Seam sealants are usually manufactured in batches, and batch to batch variations in rheological properties can occur. Variations within production limits are acceptable as shown in Figure 6. However, too high G'-values will result in poor coverage, i.e. poor sealing, of flanges whereas too low G'-values imply dripping and manual reworking of car body seams. Pumping out-of-specification seam sealants into application equipment will result in production stops and possibly scrapped car bodies. Therefore, batch control of the rheological properties of seam sealants has proven to prevent production stops, and ensure a cost-efficient seam sealing process.

CONCLUSIONS

Automotive production is a complex cost-intensive process that is continuously haunted by measures to reduce both production cost and time while striving after improved product quality. One way to meet such objectives is to deal with salient rheological challenges in automotive production.

ACKNOWLEDGMENTS

The authors would like to thank their colleagues at Volvo Car Corporation for their contributions and interest in rheology.

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