Creep Modeling Of Plastic Components in Sealed Connectors

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Abstract

This work addresses the modeling of sealed connectors used in automotive engine compartments. Silicon components, such as grommets and interfacial seals, are used and designed to ensure good contact pressure on plastic components and thus provide the required sealing performance.
As a result of the heat generated in engine compartment, there is potential for plastic deformation of the areas under stress in the housings. The stress is mainly exerted by the seals on the area of the contact with the plastic components. If this stress induces a permanent deformation, it can cause a loss of sealing performance. The permanent deformation has two components: an instantaneous plastic strain as well as a creep strain developing overtime. The goal of this study is to determine the relative importance of these two components so that the designer could optimize the product configuration to ensure that the sealing performance is met throughout the product service life.
This paper describes and illustrates the numerical approach, used to identify the contributions of instantaneous and creep deformations on a representative connector case. Simulation with LS-DYNA are compared to experimental test results to validate the modeling approach.

1 Introduction

Seals are essential components in automotive connectors for engine compartments as they are used to prevent humidity and dust introduction within the electrical contact areas and thus prevent short circuits and risk of corrosion. These seals are generally made from silicone-based rubbers. In recent years, the Liquid Silicone Rubbers (LSR) become widely used for connector sealing applications.

There are typically 3 types of seals in automotive connectors depending on the interface to be sealed:

- Cable seal: between the cable and its surrounding plastic cavity
- Grommet: between multiples cable(s) and the housing
- Interfacial Seal: between the header and housing of a connector

Fig.1 shows examples of each type of seals and Fig.2 provides cross-sections of connector assembled with the 3 types of seals.

Fig.1: The different types of automotive connector seals

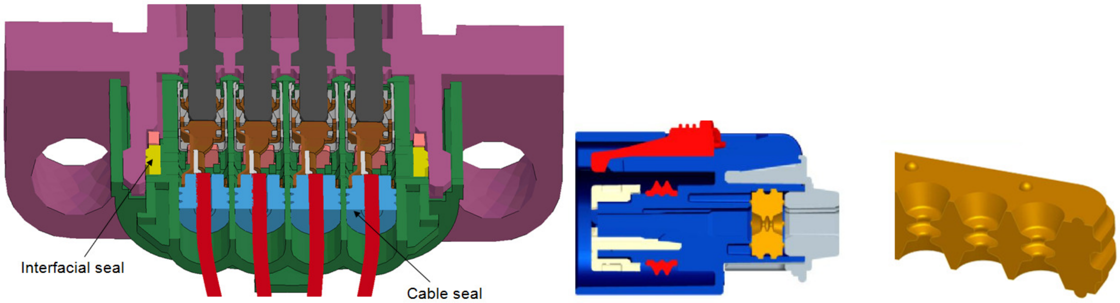

Fig.2: Views of seals assembled in a connector

The seals are designed to allow an easy assembly such as terminal and cable insertion through the seal (cable seal and grommet) and on one hand to create an optimal level of pressure between the seal and the cable, and on the other hand, between the seal and the plastic components. Therefore, the design of the seals involves a trade-off between these opposite requirements.

In this study, the focus is on the effect of the interfacial seal and the potential permanent deformation of the header as this plastic component can be subject to dimensional changes that, in turn, affect the sealing performance between the header and female connectors. The deformation resulting from the stress exerted by the interfacial seal on the header walls has potentially two components, namely, an elastic strain ε_e, and an inelastic strain:

$$\varepsilon = \varepsilon_e + \varepsilon_{in} \tag{1}$$

The higher the inelastic or permanent deformation, the higher the loss of sealing performance. This study describes the modeling approach used to evaluate the contribution of these permanent strains and their relative importance. It is worth mentioning here that the loss of sealing performance is primarily caused by the deformation of the larger header' walls.

Fig.3: Header walls deformation before and after thermal ageing

2 Modeling Approach

The header and housing are made of thermoplastic materials (Polybutylene Terephtalate PBT reinforced by to 30% glass fiber content).

There are three distinct loading phases:

- The connector assembly at room temperature
- The temperature increase up to the engine compartment service temperature 120°C
- The assembly is maintained at 120°C for 10 hours

The first two loading phases were modeled using a multi-curve table with the stress strain curves at various temperature.
In this section, the work case of Fig.4 is studied.

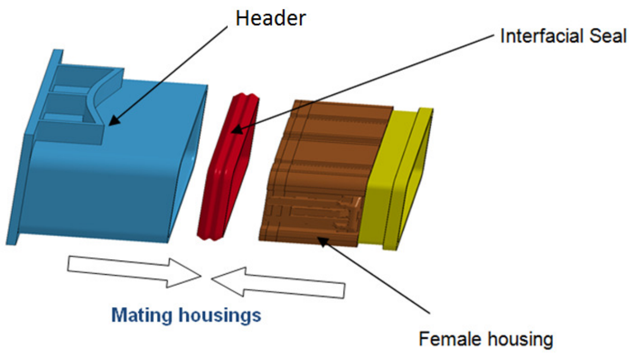

Fig.4: The components and their assembly

2.1 Instantaneous deformation of the header

2.1.1 Material behaviour

As indicated, the seals are made of an LSR material and their mechanical behavior can be represented by an hyper-elastic law. The stress tensor is calculated as the derivative of the strain energy with respect to strain tensor:

$$\underline{\underline{S}} = \frac{\partial W}{\partial \underline{\underline{E}}} \tag{2}$$

The typical range of seal compression is within 10% to 30% range, and the material is assumed to be incompressible and initially isotropic. We consider the Mooney-Rivlin law to model the hyper-elastic behavior [2]:

$$W(I_1, I_2) = C_1(I_1 - 3) + C_2(I_2 - 3) \tag{3}$$

Where I_1 and I_2 are the first and second Cauchy tensor invariants, C_1 and C_2 are material constants determined through tests (uniaxial tension, uniaxial compression, ..). For the LSR used in this application, the parameters identified from tension-compression testing are: C_1=0.163 MPa and C_2=0.04 MPa.
Plastic materials are modeled by a thermo-elasto-visco-plastic law. Effective stress versus effective strain is defined by curves for temperatures from -40°C to 150°C obtained from tensile tests.

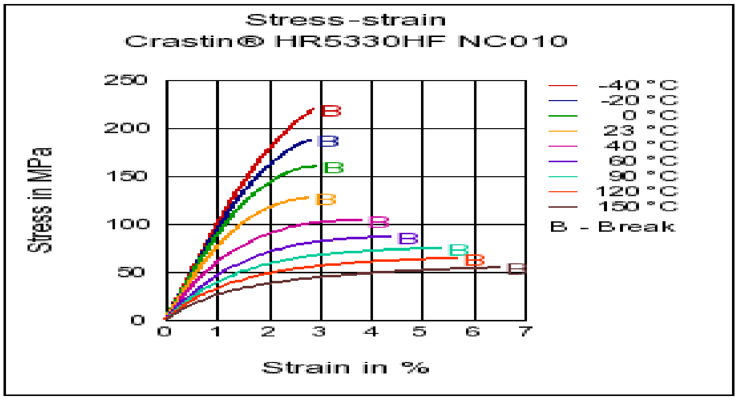

Fig.5: Tensile tests for different temperatures (source: dupont)

Material properties are thermo-dependent. The impact of Temperature is taken into account by using *MAT_THERMAL_ISOTROPIC card with the appropriate heat capacity and thermal conductivity parameters. For both plastic and silicon, we consider an isotropic thermal expansion. The coefficients of thermal expansion (CTE) are 65.10^{-6} for the thermoplastic material and 190.10^{-6} for the LSR material.
For comparisons purposes between instantaneous deformation and creep deformation, this last loading phase was modeled separately using a Norton law for which the parameters are identified from experimental data at different load levels and different durations.

2.1.2 Numerical simulation

Numerical simulation with ls-dyna, was used to evaluate numerically the instantaneous displacement. In this explicit simulation, male housing (header) is inserted slowly such as a a quasi-static configuration is verified.
Two phases are considered:

- First phase: connector assembly, at room temperature. This simulation is carried at the steady state to determine the instantaneous displacement due to assembly.
- Second phase: the room temperature is set at 120℃. This transient analysis will activate thermal transfer and modify material mechanical properties after convection. A second instantaneous deformation is determined at this stage.

After the end of the first phase, the connector of Fig.4 is deformed as shown below.

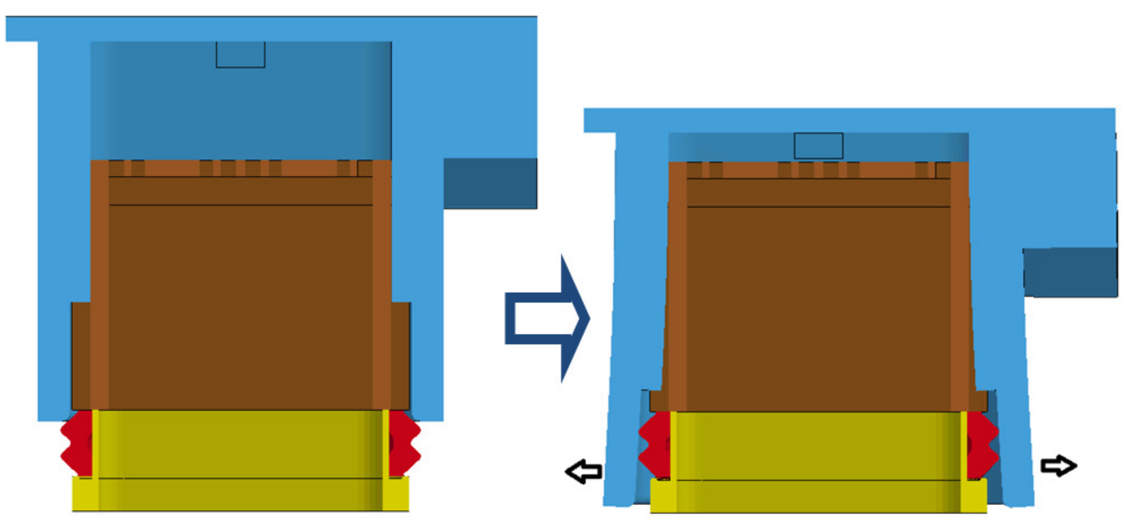

Fig.6: Header deformation after insertion.

After insertion, the displacement over the length of the header is about of 0.4mm.

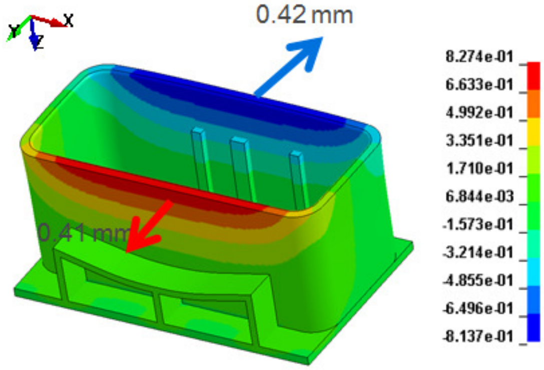

Fig.7: First instantaneous deformation at room temperature.

At the assembled configuration, the temperature is raised to 120℃ (the engine temperature). Only convection and conduction are taken into account for heat transfer in the thermo-mechanical analysis, (non-linear transient analysis). During this stage, the LSR thermal expansion induce an additional pressure on header. Moreover, the increase of temperature softens the plastic part as shown in Fig.8. Fig.9 shows the displacement of plastic walls when the LSR expands (The temperature distribution is shown on LSR only.

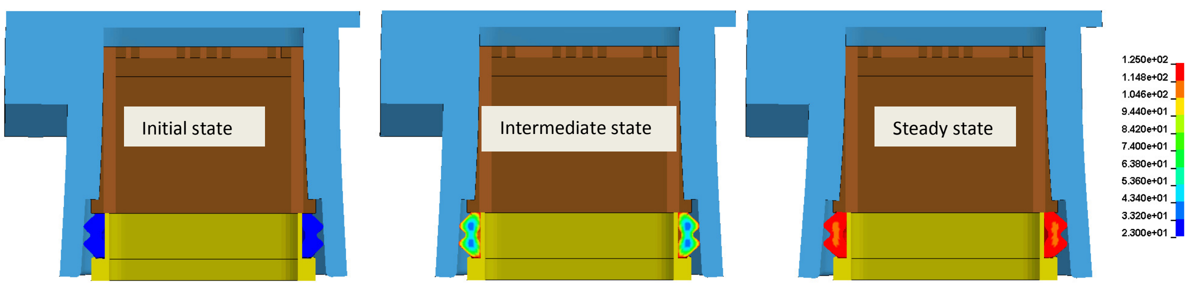

Fig.8: Views of the wall deformation with a large scale factor (actual displacement magnitude is low).

In the steady state, an additional instantaneous displacement of about 0.18mm is obtained over the length of the header's walls.

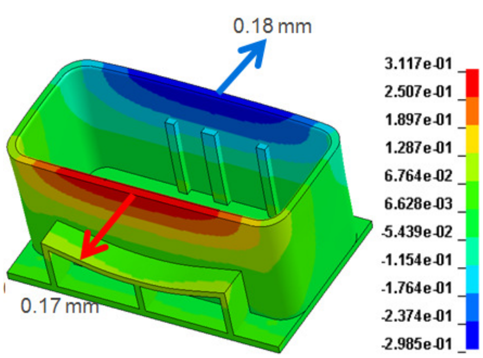

Fig.9: Second instantaneous deformation after heat transfer.

2.2 Creep deformation

After thermal change, the contact pressure is stabilized, plastic parts are submitted to a constant loading (in time) and temperature. Plastic housings may be then subject to creep [1]. This deformation

results from visco-plastic behavior and may start at room temperature (or at a certain percentage of melting temperature) for plastics.
Creep is an irreversible long term deformation and its behavior modeled typically by three stages:

- Primary Creep: Starts at a rapid rate and slows with time due to work hardening
- Secondary Creep: Has a relatively uniform rate. "Creep strain rate" typically refers to the rate in this secondary stage.
- Tertiary Creep: Has an accelerated creep rate and terminates when the material breaks or ruptures.

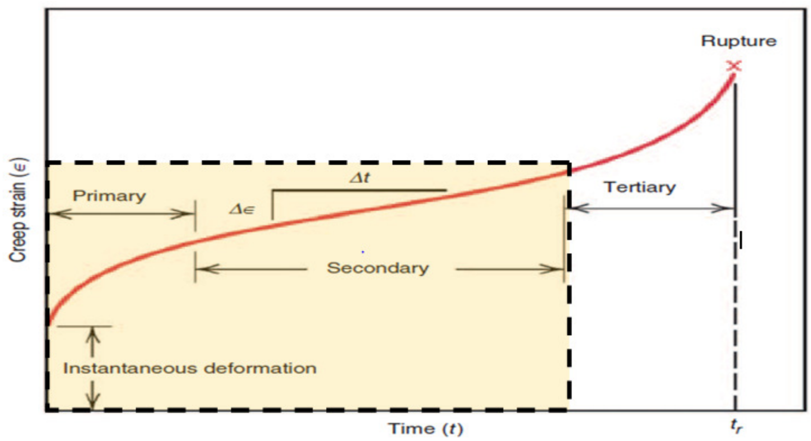

Fig.10: Creep stages under a constant mechanical load and temperature

In most industrial applications, only the primary and secondary stages occur. The tertiary stage requires generally a combination of very high stress/temperature over an extended period of time.
The permanent deformation is measured after 1h, 10h, 100h and 1000h.

The deformation due to creep, under a constant loading $\overline{\sigma}$, is given by [3]:

$$\overline{\varepsilon}^{c}(t) = \frac{(\Delta L)(t)}{L_0} \times 100(\%) \tag{4}$$

Where L_0 is the initial gauge length.

Creep modulus is given by:

$$E(t) = \frac{\overline{\sigma}}{\overline{\varepsilon}^{c}(t)} \tag{5}$$

Experimental data on creep modulus is available at several temperatures (from 23°C to 120°C) and several load levels.

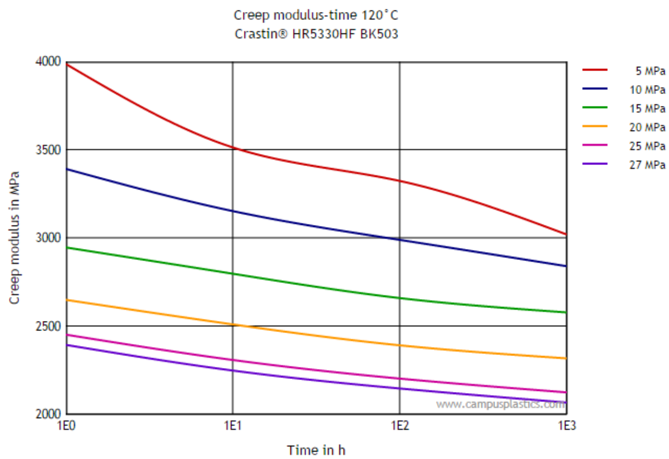

Fig.11: Creep modulus at 120℃ (Source: Dupont)

The third analysis aims to evaluate creep deformation. We assume this deformation takes place gradually at the steady state, when the environment temperature is 120℃. For creep under a given constant load $\bar{\sigma}$ we consider Norton model [4]:

$$\bar{\varepsilon}^{c} = A\bar{\sigma}^{n}\bar{t}^{m} \tag{6}$$

Where A, n and m are a temperature dependent constant parameters.

A program based on least square method, allowed the identification of parameters A, n and m at 120℃. These parameters were found equal to be respectively 0.0301, 1.1744, and 0.01918.
Fig.12 shows, numerical (with the determined parameters A, n and m) and experimental creep curves.

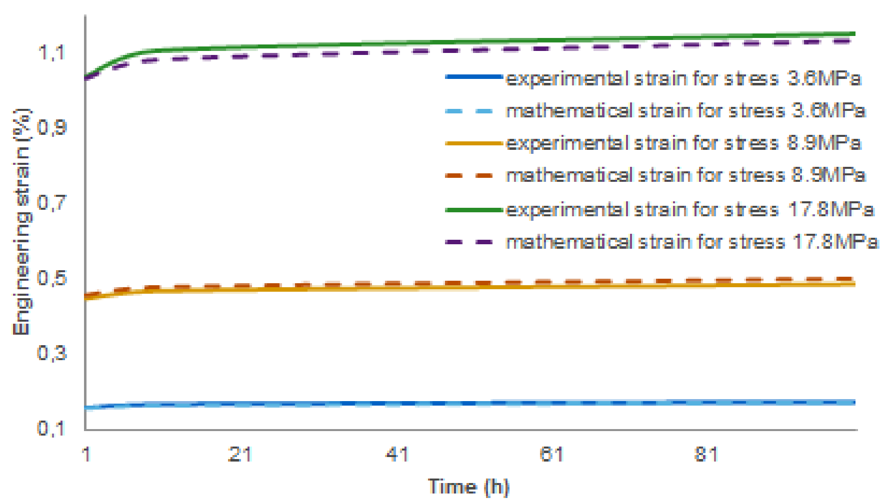

Fig.12: Creep curves for different load, at 120℃.

This creep law was integrated in the elasto-visco-plastic mechanical law by using the CARD *MAT_THERMO_ELASTO_VISCOPLASTIC_CREEP. The simulated real time is 10h. LSR pressure remains less than 3MPa, the calculated creep deformation was very low compared to the instantaneous deformation. The contribution of this deformation is less than 1% (less than 0.01mm) with respect to the overall deformation.
This analysis shown that the most damaging deformation is in fact the instantaneous deformation

3 Comparison with experimental observations

The impact of the interfacial seal, on a high pin count connector, was evaluated experimentally (on the connector of Fig.4) after assembly and thermal ageing at 120℃.
The deformation on header key dimension due to interfacial seal corresponds to 2%.

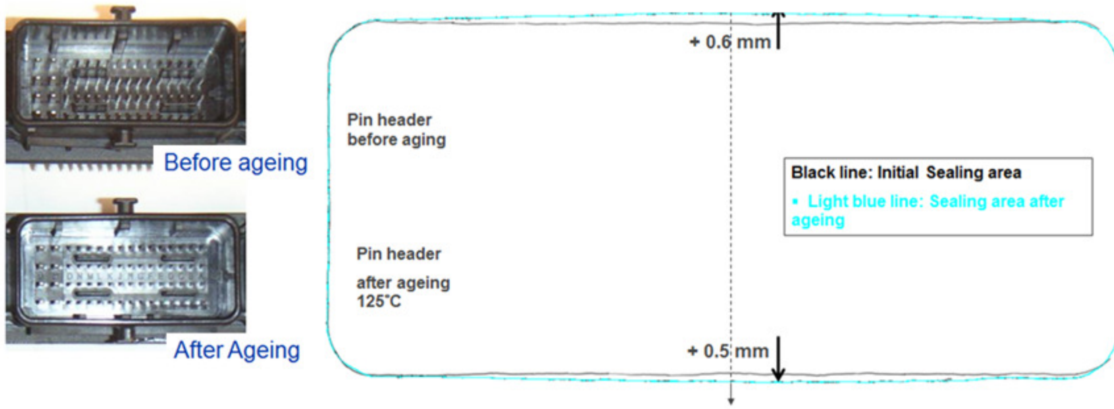

Fig.13: Plastic housing deformation after assembly and thermal ageing

Table 1 shows an agreement between experimental and numerical results on the total walls displacement of header.

Question of	Experimental result	Numerical result
Right header displacement	0.6	0.6
Left header displacement	0.5	0.58

Table 1: Header's wall deformation permanent deformation

4 Summary

The modeling approach presented here can help address practical issues for sealed electrical connectors. The approach adopted is to determine the permanent deformation of the header's walls as the main contributor to loss of sealing performance. The question was then at which stage of the assembly and life service would this happen. The modeling results indicate that the main deformation is due to the instantaneous deformation of the header walls, under the combination of the interfacial seal pressure and the plastic material softening at T~120℃ in the first thermal loading. The creep phenomena occurs but its contribution to the permanent deformation is negligible compared to that of the instantaneous plasticity taking place in the first thermal loading as a result of the plastic material softening. The design of the headers and the interfacial seals should be optimized to reduce the level of this instantaneous permanent deformation. This work shows how this can be assessed by numerical modeling.

5 Literature

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6 Acknowledgment

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