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Modeling of CWR Tracks Including a Switch

J.-F. Ferellec[1], T. Haljouji[2], B. Jeanselme[1], Z. Wang[1] and M. Wone[1]

[1]DTR-DGII-GC VA-TM, SNCF RESEAU, La Plaine St Denis, France
[2]Ikos, Consulting, Levallois Perret, France

Abstract

A numerical model of continuous welded rail track based on finite element analysis has been built and been able to reproduce typical behaviour of this kind of tracks when subject to temperature rise. Applied to the case of a switch integrated to continuous welded rail tracks, the model has helped estimating the peak or rail axial stress that appears in this kind of configuration.

Keywords: track, continuous welded rail, simulation, finite element analysis, switch, ballasted track.

1 Introduction

Continuous welded rail (CWR) tracks have become the most common type of railway in many countries because of the improved comfort it offers to train passengers and its compliance with the stricter requirements of high-speed lines. His sensitivity to temperature variation implies particular attention in terms of maintenance. A large deviation from its neutral temperature, that is temperature during its installation on track, can have disastrous consequences. As the rail is attached to the sleepers which are themselves embedded in the ballast, it can barely contract or dilate and either tension or compression forces will build up all along its length. This can result into rail rupture in large temperature drop or rail buckling in high temperature raise. Railway engineers are generally more exposed to rail buckling problems than rail rupture and they usually rely on methods or tools based on empirical observations to design or maintain CWR tracks. These tools cannot however address all the possible track configurations and unreasonably large safety factors are implemented to palliate insufficient understanding of the mechanisms involved in complex railway CWR systems like the ones including switches.

CWR tracks have been analysed analytically and the impact of different parameters like ballast longitudinal and lateral resistance or rail-sleeper links explained [1:4]. The rise of high-performance computing has also led to the development of more elaborated finite element models (FEM) models to analyse the behaviour of CWR tracks in more particular cases. [5,6] analysed the behaviour of CWR tracks with alignment defect and gauge irregularity using FEM modelling. [7] developed another FEM model to measure the impact of geometry defect in both alignment and curve CWR tracks.

The purpose of the present paper is to show the development of an FEM model to analyse complex CWR track configurations involving switches where high stress can appear during temperature rises.

The first section describes the CWR track model, its parameters. The second one shows its validation and the third one its implementation in the case of a switch.

2 Track model

The track is modelled using Mechanical from ANSYS as illustrated on figure 1. The rails and sleepers are modelled using beam elements (BEAM188). The rail pads and fasteners are represented by non-linear springs (COMBIN39) between the rails and each sleeper for longitudinal, lateral et vertical translations and vertical rotation. The ballast resistance is modelled by non-linear springs for longitudinal and lateral translations and the ballast layer stiffness by a non-linear spring for vertical translation. The non-linear springs are perfectly elastic-plastic characterised by a maximum force (or a maximum moment) and maximum elongation (or rotation) before plasticity. Table 1 summaries the value of the parameters used for the different elements of the model. The rails are then subject to different temperature increases between 0 and 100°C using the static type of solver with either Newton-Raphson or Arclength schemes depending on buckling probability.

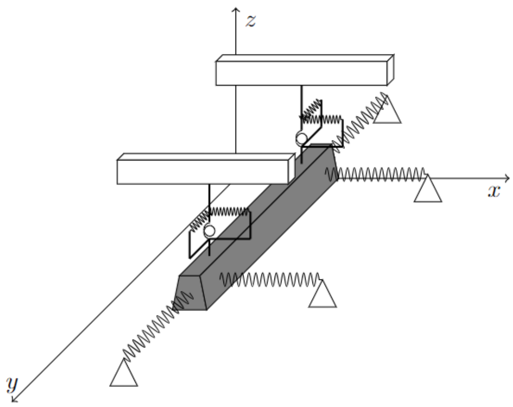

Figure 1: 1435mm gauge track model

Component	*Property (unit)*	Value
Rail	*Young modulus E (MPa)* *Poisson ratio* *Density (kg/m^3)* *Section type 60E1 (mm^2)* *Thermal expansion coefficient (mm/°C)*	2.1×10^5 0.3 7860 7580 1.15×10^{-5}
Sleeper	*Young modulus E (MPa)* *Poisson ratio* *Density (kg/m^3)* *Section type B440 (mm^2)* *Length (m)*	4.2×10^4 0.25 1700 58300 2.4
Fastener	*Longitudinal maximum force (kN)* *Longitudinal maximum elastic elongation (mm)* *Lateral maximum force (kN)* *Lateral maximum elastic elongation (mm)*	16 2 160 2
Rail seat	*Vertical rotational elastic stiffness (N.mm/rad)*	4.5×10^8
Ballast	*Longitudinal maximum force (kN)* *Longitudinal maximum elastic elongation (mm)* *Lateral maximum force (kN)* *Lateral maximum elastic elongation (mm)*	20 2 10 2

Table 1: Parameters of the model

3 Model results

A perfectly straight 500m long track has been build using this model and submitted to temperature rises. Both ends of the track are free to move. Figure 2 shows the rail axial stress and longitudinal displacement along the track after a temperature rise ΔT of 50°C. In the central part the rails cannot dilate and move because of the constraints of the fasteners between the rails and the sleepers and the longitudinal resistance of the ballast acting on the sleepers. As a result, the axial stress developed in the rail and observed in the simulation is perfectly equal to 120MPa, the stress obtained from the equation:

$$\sigma = E\alpha\Delta T \quad (1)$$

Where E is the Young modulus of the rail steel and α its coefficient of thermal expansion. Towards the ends of the track, both rails are free to expand leading to a 17.5mm longitudinal displacement of the rails and the axial stress progressively decreases to zero. These so-called breathing areas are about 100m long on both ends of the CWR track.

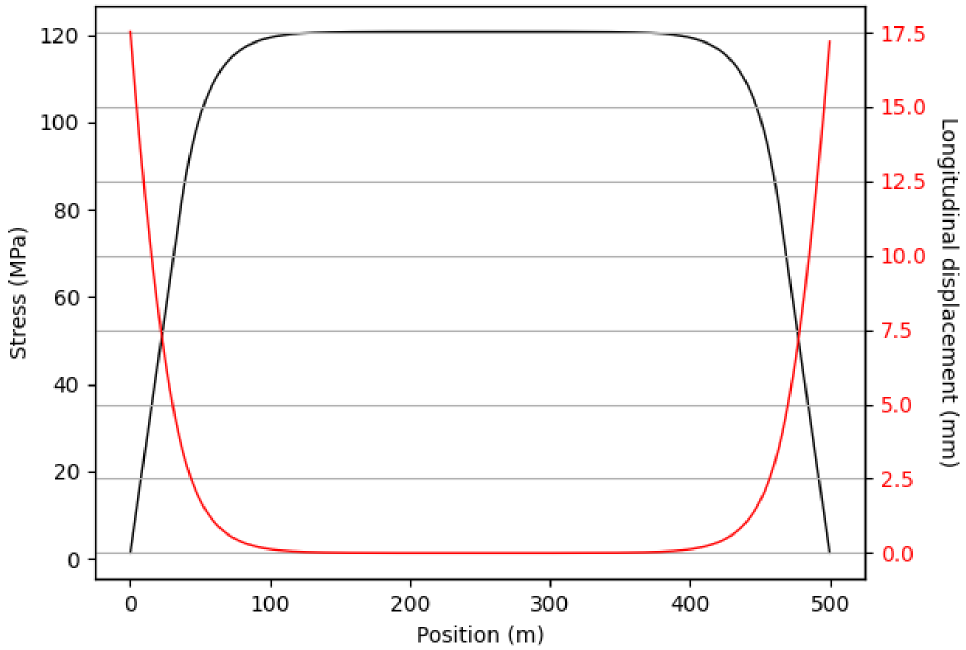

Figure 2: Axial stress and longitudinal displacement of rails along the track after a 50°C temperature rise

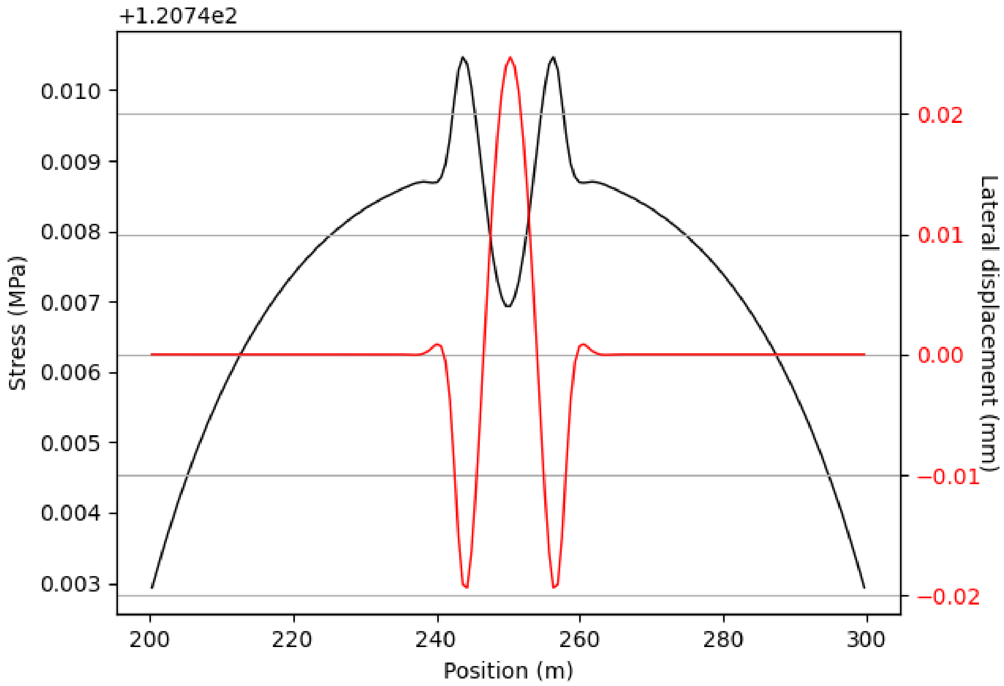

Figure 3: Lateral displacement and stress in rail along the track

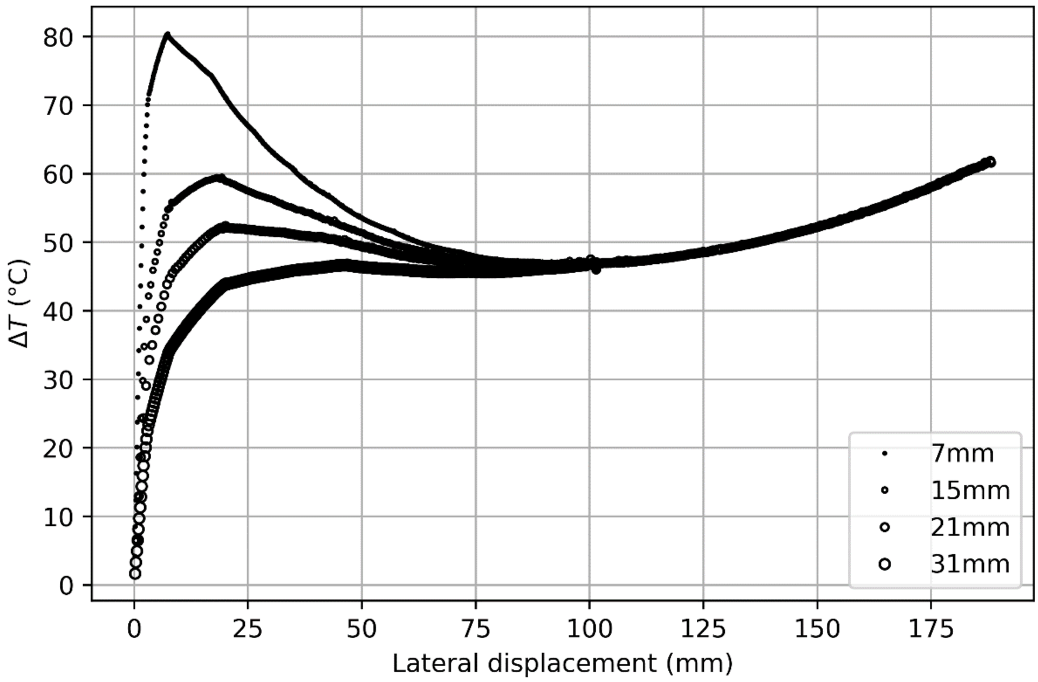

Figure 4: Relationship between temperature variation and lateral displacement of track middle

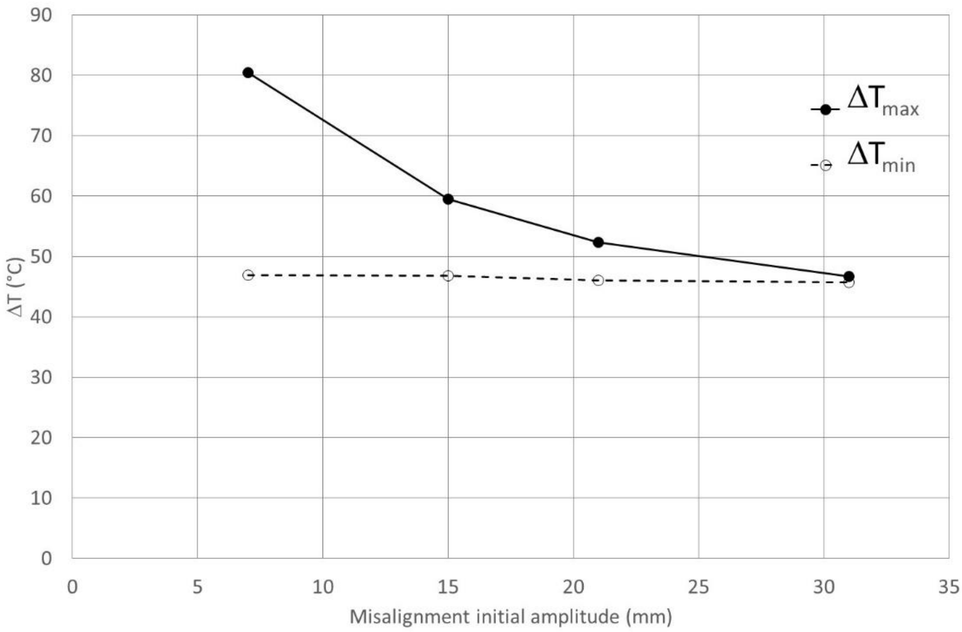

Figure5: Minimum and maximum equilibrium temperature variation for different initial misalignment amplitudes (bottom)

This perfectly straight track won't deform laterally unless the rails present defects in alignment. To observe this king of deformation, a sinusoidal shape track misalignment is implemented at the centre of the track. Its length is 15m and amplitude 1mm. Then a temperature rise ΔT of 50°C is applied to the rails. The axial stress is changed locally around the initial misalignment. Figure 3 shows the evolution of the axial stress and the lateral displacement of the rails in a 100m area around the initial misalignment. The damped sine wave deformation pattern is typical of the initialisation of buckling. However the axial stress eveloped due to the temperature rise is not high enough to overcome the longitudinal and lateral resistances offered by the ballast layer. The rail axial stress barely changes along the track.

Figure 4 shows the evolution of the lateral displacement of the rail in the middle of the track during the calculation process when the temperature is raised progressively for a 3.6m long and four different amplitudes misalignment. The curve is typical of the bifurcation phenomena observed during buckling. Initially the displacement increases with temperature reaching a maximum unstable equilibrium at ΔT_{max} which quickly evolutes to a minimum corresponding to a stable equilibrium at ΔT_{min}. If the temperature increases again then the displacement increases again. The smaller the amplitude of the misalignment the higher the buckling temperature (Fig.5).

All these results show that the FEM model built with ANSYS can reproduce the behaviour of CWR tracks subjected to temperature rises and that it can be used to analyse complex configurations of CWR tracks including switches. The following section describes its use for a straight track including one switch.

4 Switch case

The aim of this case is to measure the axial stress increase that appears at the front of the switch during temperature rises with 200m long CWR tracks at each end (fig. 6.a). It includes a straight main line with a junction switch at 6° (fig. 6.b). The crossing (fig. 6.c) of this switch has been modelled as a 3D volumetric mesh (SOLID185 in ANSYS) because of its complexity and has been connected to the beams representing the rails. This configuration includes sleepers which are longer to support both lines in the switch. The longitudinal and lateral ballast resistances and the fasteners have been modified accordingly.

Figure 7 shows the deviation of axial stress (from the stress developed in a track without switch) along the external rail of the straight track (top rail on figure 6) for different temperature increases. The horizontal axis represents the sleeper number along the straight track. For each temperature increase is associated an axial stress corresponding to the one developed without a switch. Figure shows the deviation from this axial stress for each temperature increase. When the temperature increases, the single track (left on figure 6) is pushed by the other two tracks (right on figure 6) and an increase of axial stress is observed on the single track near the switch. At the opposite side of the switch the rail is pulled hence generally reducing the axial stress on this side. The evolution of the axial stress on that side is different around the crossing of the switch. The longitudinal displacement track around the crossing is more difficult because the crossing makes the displacement of the different components around it interdependent. Hence it has an impact on the axial stress reduction on that side.

Figure 8 shows the maximum axial stress deviation observed along the external rail of the straight track against the temperature increase. This relation can be used to estimate the axial stress that can appear for any temperature variation up to 100°C. Beyond this threshold, additional simulations are required to check the possible development of bucking on the CWR tracks connected to the switch. This switch configuration is quite simple and more complex ones can be treated using the same approach. The parameters of the different components of the track and especially the switch can be modified to check their impact on the axial stress along the CWR rails.

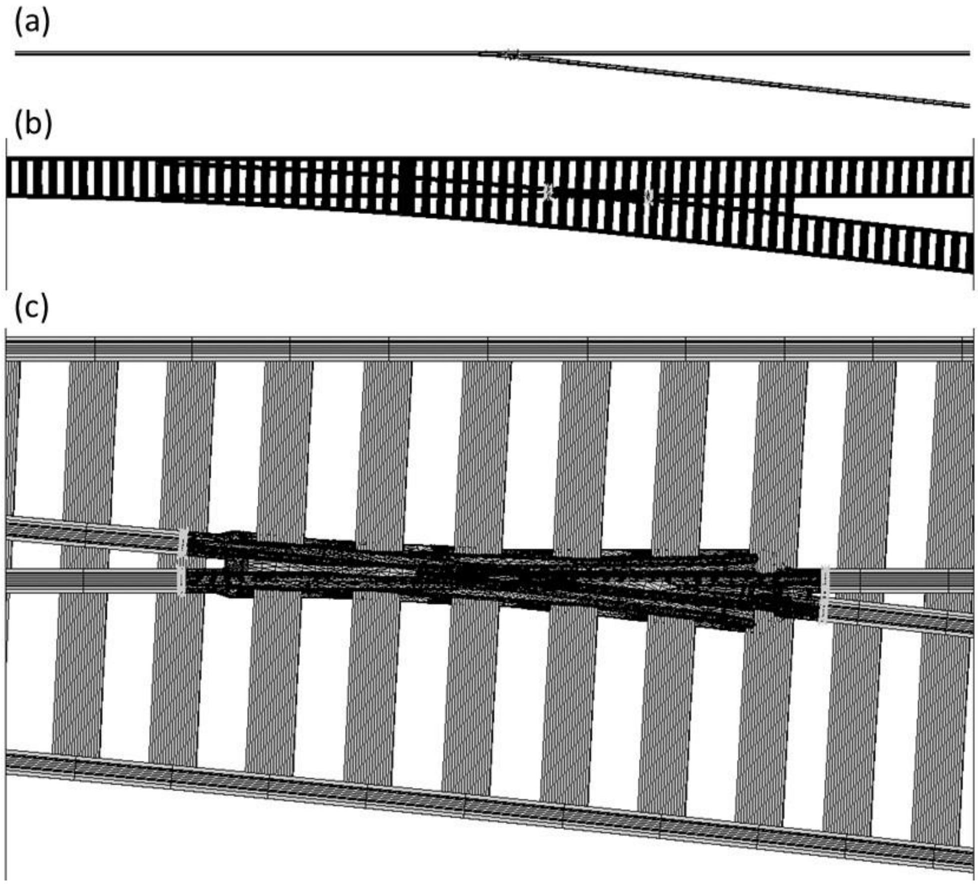

Figure 6: Switch model configuration: (a) global, (b) switch, (c) crossing

5 Conclusions and Contributions

A FEM model of CWR track has been built using ANSYS. Simulations of simple CWR track show that it can reproduce typical behaviour of this kind of track during temperature rise: buckling, breathing areas, bifurcation.

When applied to a switch configuration with CWR tracks, it can reproduce the peak rail axial stress expected when temperature rises. It also shows a linear relation between the peak axial stress and the temperature. These results will be compared with in situ data and will help validate quantitatively the model and adjust the parameters of the model if necessary.
This model will be applied to cases of hanging sleepers by introducing variable lateral or longitudinal ballast resistance to measure their impact on the behaviour of the track and the risk of rail buckling generated by this phenomenon. The hysteresis of sleeper movement along the breathing zone can similarly be analysed.
This model will also be used to estimate more precisely the axial stress in different combinations of switch that can be implemented in CWR tracks. Then the results will be taken into account by railway engineers to estimate the risk of buckling in CWR tracks with adequate safety factors.

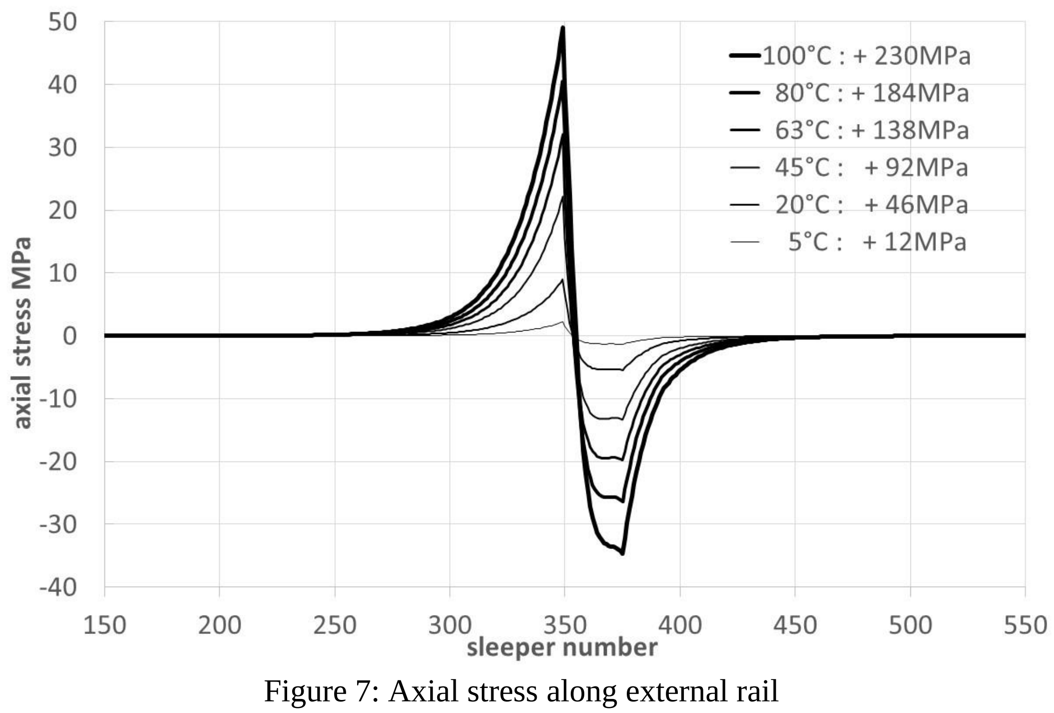

Figure 7: Axial stress along external rail

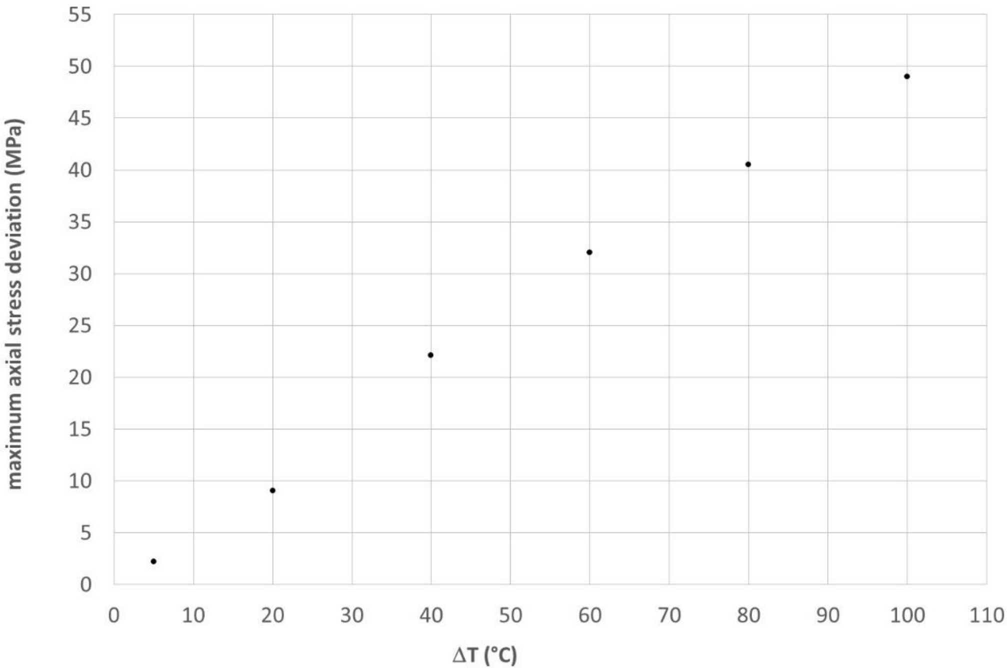

Figure 8: Peak stress in switch as a function of temperature variation

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