AERSYS www.aersys.com	AERSYS KNOWLEDGE UNIT	AERSYS-3010

Author:	Asier Ruiz de Aguirre Malaxetxebarria	Date:	07/01/2011

FEM		HAND		LIN		NOLIN		BUCK		FAT		STATIC	X	COMP	X	MET	X

THERMAL LOADS CRITICALITY

1. INTRODUCTION

The internal loads created by the thermo-elastic behavior of the materials can lead to reserve factors below one in some cases. However, it has been demonstrated by test that the thermal stresses created by temperature distributions tend to have a lower impact on the materials that the mechanical stresses. In the next chapter the theoretical discussion of the criticality of the stresses coming from a thermo-elastic analysis is presented. This is intended to provide a set of arguments to support discussions to attenuate the thermo-elastic stresses contribution to the calculation of reserve factors.

2. THERMAL LOADS CRITICALITY DISCUSSION

The thermal stresses can arise on a structure when:

- The temperature distribution on the part is not uniform.
- The temperature distribution on the part is uniform but the support provided is hyperstatic.
- Materials with different thermal expansion coefficients are connected.

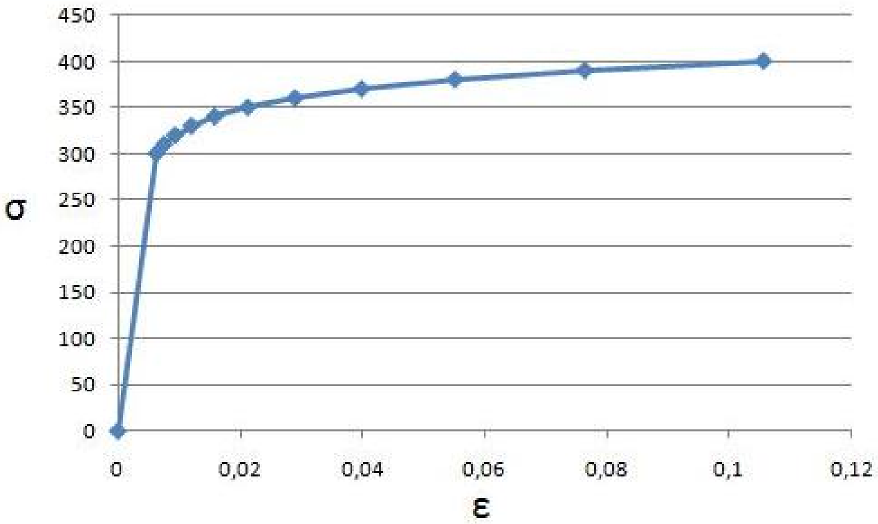
Usually the thermal analyses are made at constant temperature and therefore the typical reasons to get thermal stresses are hyperstaticity and different expansion coefficients.

When a structure with a constant expansion coefficient is isostatically supported no thermal stresses is obtained.

Unlike the mechanical loads, the thermal loads are internal loads. This means that the total addition of the thermal loads on a part has to be null. If some area gets compressive loads the remaining part will take tensile loads to compensate. This internal nature allows some mitigation in the following cases:

Metallic materials strength:

The metallic material show plastic behavior from the yield stress. This means that the material stress-strain curve has a non-linear shape from the yield stress to the ultimate strength:



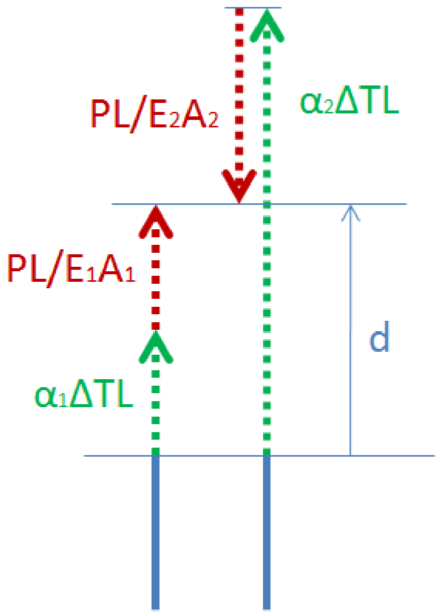
Consider a structure comprised o two bars rigidly connected with dissimilar thermal expansion coefficients:

When some increment of temperature (ΔT) is applied to the structure the displacement of the bar 1 tends to be ($\alpha_1 \cdot \Delta T \cdot L$) whilst the displacement of the bar 2 tends to be ($\alpha_2 \cdot \Delta T \cdot L$). As the bars are rigidly connected some loads (P_1 and P_2) will appear on the bars. This loads will be such that P_1=-P_2 and that the displacement of both bars is the same:

The following equations will be fulfilled:

$$d = \alpha_1 \Delta T L + \frac{PL}{E_1 A_1}$$
$$d = \alpha_2 \Delta T L - \frac{PL}{E_2 A_2}$$

This is graphically represented on the figure below:



These equations are valid throughout the elastic range of the materials. When the increment of temperature is enough the P load will get a value that will pass the yielding stress of the material of one bar (bar 1 for example):

$$\sigma_1 = \frac{P}{A_1} > F_{ty}^1$$

When this happens the tangential elastic modulus of the material falls dramatically, therefore the bar cannot take any significant additional load because it has lost its stiffness. The bars will continue getting deformation but no significant additional loads (ΔP) will be created. As the bar 1 cannot take any load the bar 2 cannot take any load either (the total load is null).

Therefore when the yielding is passed any additional moderate increment of temperature will not make the material to fail because the stiffness reduction from yielding point will prevent the structure to generate additional internal loads as a result of the increment of temperature.

If the increment of temperature is huge then the slight remaining stiffness can make the stress to get the ultimate strength of the material, but this is not the usual case.

The main conclusion is that the reserve factor calculated for thermal loads can be mitigated because of the lost of stiffness (and consequently the relief of increase of internal loads) from the yielding point in metallic materials.

Buckling:

On the structure of two bars analyzed the bar 2 takes compressive loads. This loads could get the buckling strength of the bar element. If this happens the bar 2 will not be able to take any additional increment of compressive loads. As the bar 2 cannot take any additional load the bar 1 will not develop any additional increment of loads either (the total load is null).

Therefore from the buckling point of any bar, any additional increment on the temperature will not create additional internal loads as the buckled element cannot get additional loads. The structure will never fail due to thermal loads because the buckling will never imply overloading the other part (as for the post-buckling analysis with mechanical loads). The RF for buckling on bar 2 will equal 1.0.

Composite strains:

Usually the composite structures are analyzed by FEM due to the complex nature of the calculations involved on the laminates. The typical criteria used to evaluate the composite parts are based on reading the strains (especially the damage tolerance criterion).

NASTRAN computes the strains on the thermo-elastic calculations and their related stresses. However not all the amount of strain calculated by NASTRAN is due to internal forces (and stresses). The pure thermal expansion (with zero stress) strain is also accounted on the strain tensor calculated by NASTRAN:

$$[\varepsilon_{NASTRAN}] = [\varepsilon_\sigma] + [\varepsilon_T] = [\varepsilon_\sigma] + \Delta T \cdot [\alpha]$$

It is obvious that only the strain related with stresses (ε_σ) will be related with the failure of the material. Hence, if the NASTRAN strains are directly used to evaluate the structure some additional strain is accounted. This can be conservative or not conservative depending on the sign of the increment of temperature. Usually cold and hot cases are analyzed and therefore the approach is in general conservative. Thus, some mitigation is possible if the additional strains are subtracted from the NASTRAN values.