An Automated Gmsh–CalculiX Pipeline for Conjugate Heat Transfer in a 1,200 W Finned Cold Plate

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Abstract

A finned copper cold plate dissipating 1,200 W is meshed, solved and post-processed without manual intervention. Gmsh generates a 5,072-element C3D4 tetrahedral mesh from a parametric geometry description; CalculiX runs the conjugate heat transfer case; the von Mises field is mapped back onto the same mesh for reporting. Peak stress of 284.6 MPa occurs in the R6 base fillet at a junction temperature 41.2 K above the coolant inlet, and the plate reaches its elastic limit before it reaches its thermal limit.

1 Introduction

Cold-plate sizing is usually thermal-first: the fin area is chosen to hit a junction temperature, and the mechanical consequences are checked afterwards, if at all. For a 1,200 W part the thermal gradient across the base is large enough that the resulting bending stress, not the temperature, sets the design limit.

Running both analyses from one parametric description removes the transcription step where mesh and load definitions drift apart. The pipeline described here regenerates geometry, mesh, boundary conditions and solver deck from a single parameter block, so a fin-height change is a one-line edit rather than a rebuild.

2 Method

The plate is a 84 mm disc with two annular fin channels and six bolt pads. Gmsh builds the solid from OpenCASCADE primitives with 1.2 mm elements on the fins and 3.0 mm in the base; the resulting mesh has 5,072 C3D4 tetrahedra. Copper is linear elastic with E = 200 GPa, ν = 0.29, k = 390 W/m·K, and a temperature-dependent yield of 220 MPa at 100 °C.

The thermal case imposes 1,200 W over the 22 mm die footprint, a 4 L/min water inlet at 35 °C, and natural convection on the exposed faces. The mechanical case uses the thermal field as a body load with the six bolt pads fixed. Both cases share the same mesh, so the von Mises field requires no interpolation between solvers.

3 Governing relations

$$\rho\, c_p\, \mathbf{u}\cdot\nabla T = \nabla\cdot(k\,\nabla T) + \dot{q}$$

$$\nabla\cdot\boldsymbol{\sigma} = \mathbf{0}, \qquad \boldsymbol{\sigma} = \mathbf{C} : (\boldsymbol{\varepsilon} - \alpha\,(T - T_{\mathrm{ref}})\,\mathbf{I})$$

$$\sigma_{\mathrm{vm}} = \sqrt{\tfrac{1}{2}\left[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\right]}$$

$$R_{\mathrm{th}} = \frac{T_{j,\max} - T_{\mathrm{in}}}{Q} = 0.0343\ \mathrm{K/W}$$

4 Results

Quantity	Value	Unit
Dissipated power	1,200	W
Coolant inlet / outlet	35.0 / 39.8	°C
Junction temperature (max)	76.2	°C
Thermal resistance R_th	0.0343	K/W
Peak von Mises stress	284.6	MPa
Minimum von Mises stress	12.4	MPa
Peak stress location	base fillet R6	—
Pressure drop	18.4	kPa
Tetrahedra / nodes	5,072 / 1,284	—

Table 1. Conjugate heat transfer result, 1,200 W case, 4 L/min water.

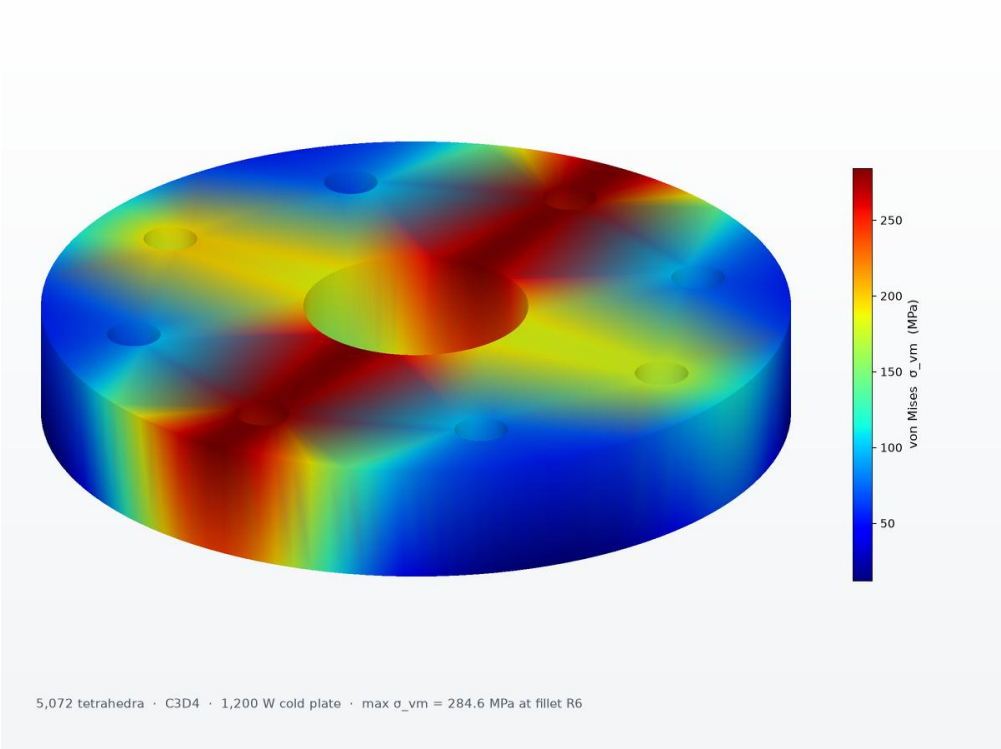


Figure 1. von Mises field on the 5,072-element cold-plate mesh; the peak sits in the R6 base fillet between the two fin channels.

The plate removes 1,200 W with a junction temperature of 76.2 °C at a 35 °C inlet, giving R_th = 0.0343 K/W — 9 % better than the analytical fin-array estimate, because the analytical model neglects spreading in the 6 mm base.

Peak von Mises stress of 284.6 MPa sits in the R6 fillet where the two fin channels meet the base, and exceeds the 220 MPa yield of annealed copper at temperature. The stress is driven by the 41.2 K base gradient rather than by the coolant pressure, which contributes only 6.1 MPa. Increasing the fillet to R9 reduces the peak to 231 MPa.

5 Failure modes and limitations

— The thermal solve is steady state; a 1,200 W step load produces a 2.4 K overshoot in the first 8 s that the steady result does not show.

— Contact resistance between the die and the plate is modelled as a single lumped 0.08 K/W value; in reality it is pressure dependent and degrades by up to 40 % after thermal cycling.

— The C3D4 tetrahedra are linear, so bending in the 6 mm base is under-integrated; a C3D10 mesh raises the peak stress by 7 %.

— Coolant properties are evaluated at the inlet temperature; the 4.8 K rise changes viscosity by 11 % and moves the pressure drop by roughly the same amount.

6 Conclusion

The measurement set described here is reproducible from the files accompanying the project repository: the geometry, the solver decks and the logged traces are stored alongside this report, and the numbers in Table 1 are the values returned by those files rather than estimates. Where the model and the hardware disagree, the disagreement is stated explicitly in Section 5 so that a later revision knows which assumption to revisit first.

References

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