Simulation of Temperature Profile During Welding with COMSOL Multiphysics® Using Rosenthal's Approach

A. Lecoanet, D. G. Ivey, H. Henein

Department of Chemical & Materials Engineering, University of Alberta, Edmonton, AB, Canada

Introduction

The goal is to find a quick and efficient way to simulate the thermal profile during welding. An approach close to Rosenthal's one [1] is utilized. After validation of the first results the possibility to go beyond the scope of Rosenthal's results is investigated.

Computational Methods

The main equation is the heat transfer equation:

$$\vec{\nabla}(k\vec{\nabla}T) + Q = \rho C_p \frac{\partial T}{\partial t} \quad (1)$$

No volumetric sources; k and C_p are constants

$$\nabla^2 T = \frac{\rho C_p}{k}\frac{\partial T}{\partial t} \quad (2)$$

Change of coordinate system: X=x-vt

$$\nabla^2 T = \frac{\rho C_p}{k}\left[\frac{\partial T}{\partial t} - v\frac{\partial T}{\partial X}\right] \quad (3)$$

Steady-state assumed in this coordinate system

$$\nabla^2 T + \frac{v\rho C_p}{k}\frac{\partial T}{\partial X} = 0 \quad (4)$$

The highlighted term does not exist in the equations provided by *the heat transfer in solids* COMSOL module. So the weak form of the first order term in this module has been tuned:

```
-ht.rho*ht.Cp*(ht.ux*Tx+ht.uy*Ty+ht.uz*Tz)*test(T)
```

```
-ht.rho*ht.Cp* (ht.ux*Tx+v*Tx+ht.uy*Ty+ht.uz*Tz)*test(T)
```

A convective heat flux is applied on all boundaries except where the source is applied. The source is applied as an entering flux.
The geometry used is shown in Figure 1.

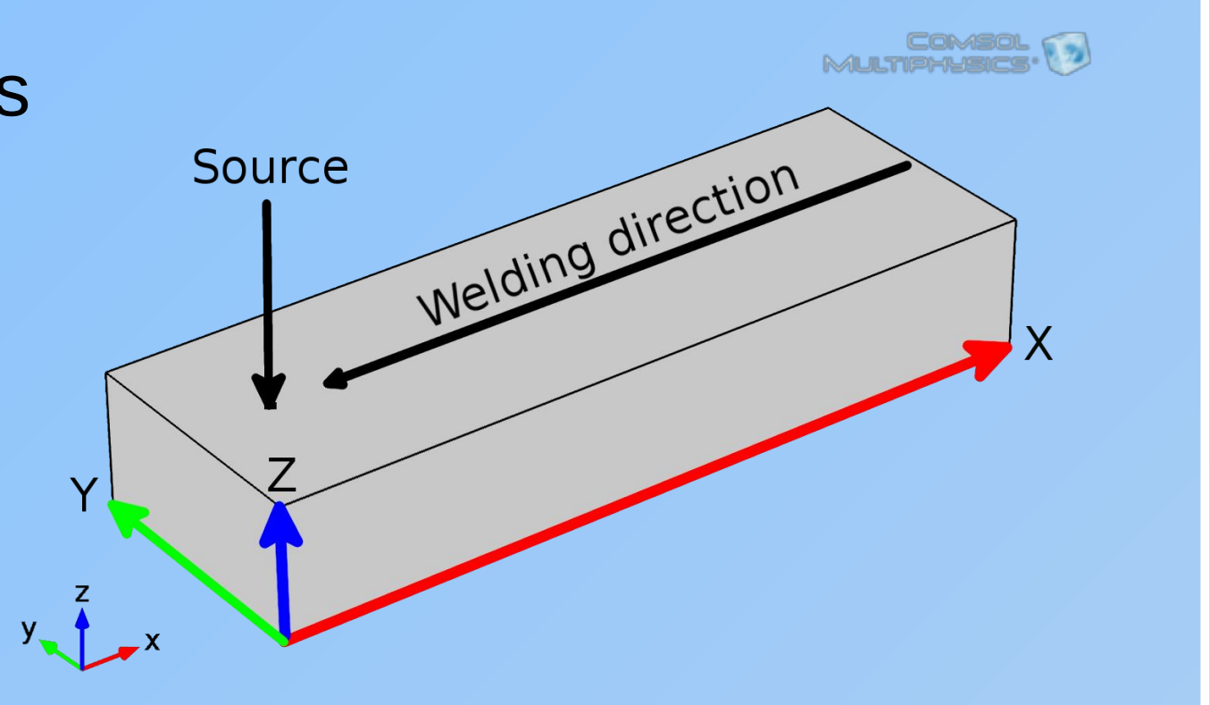

Figure 1: Geometry used in this study.

RESULTS

Rosenthal reproduction

Point source

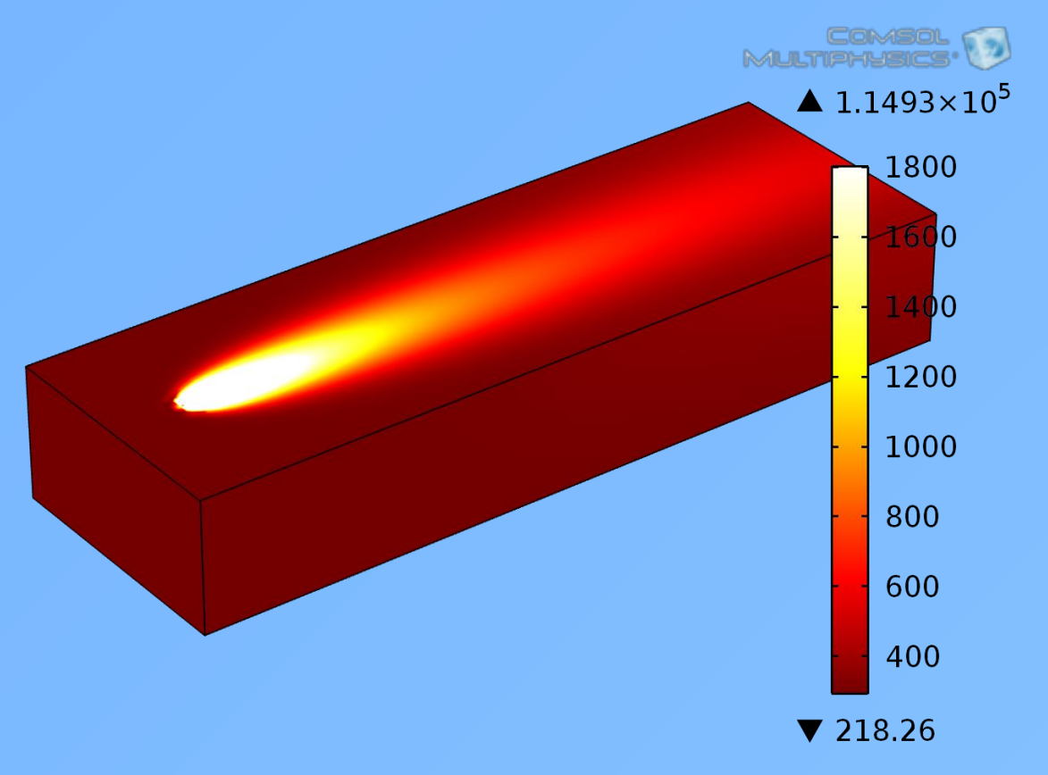

Figure 2a: Thermal profile. Point source.

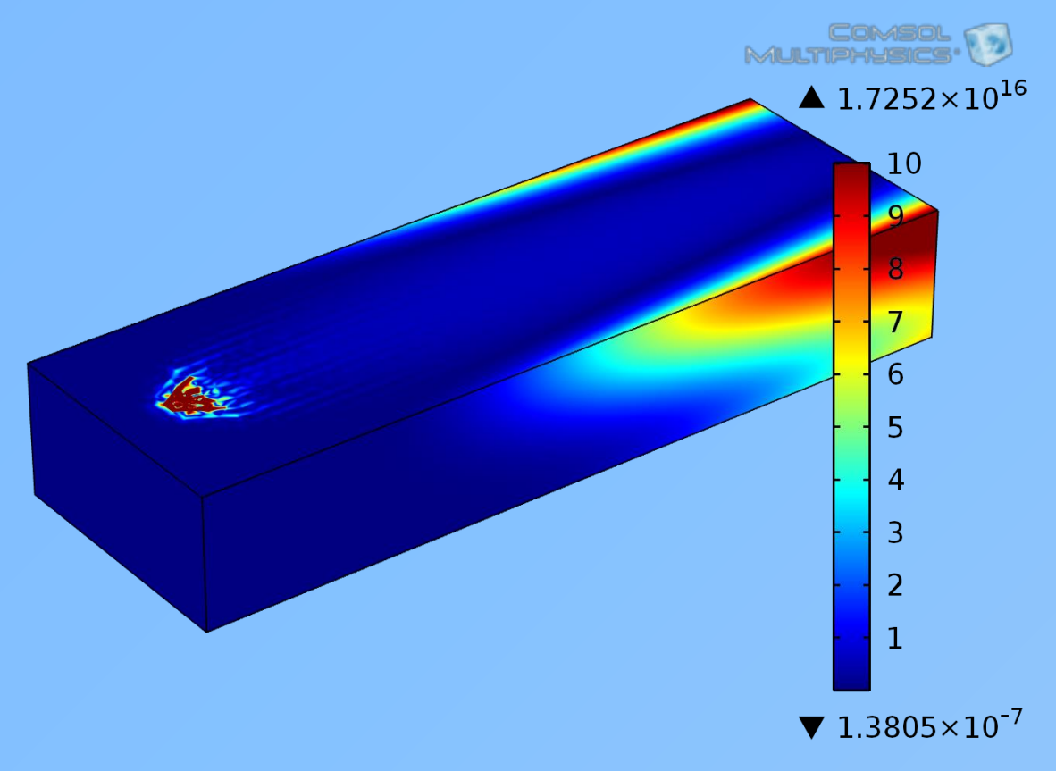

Figure 2b: Absolute relative difference with Rosenthal with a reduced color scale.

The features occurring because of point source:

- Results close to Rosenthal's results for most of the domain
- Temperature below the initial one (Figure 2a)
- Large discrepancies with Rosenthal close to the source (Figure 2b)

Hemispherical source

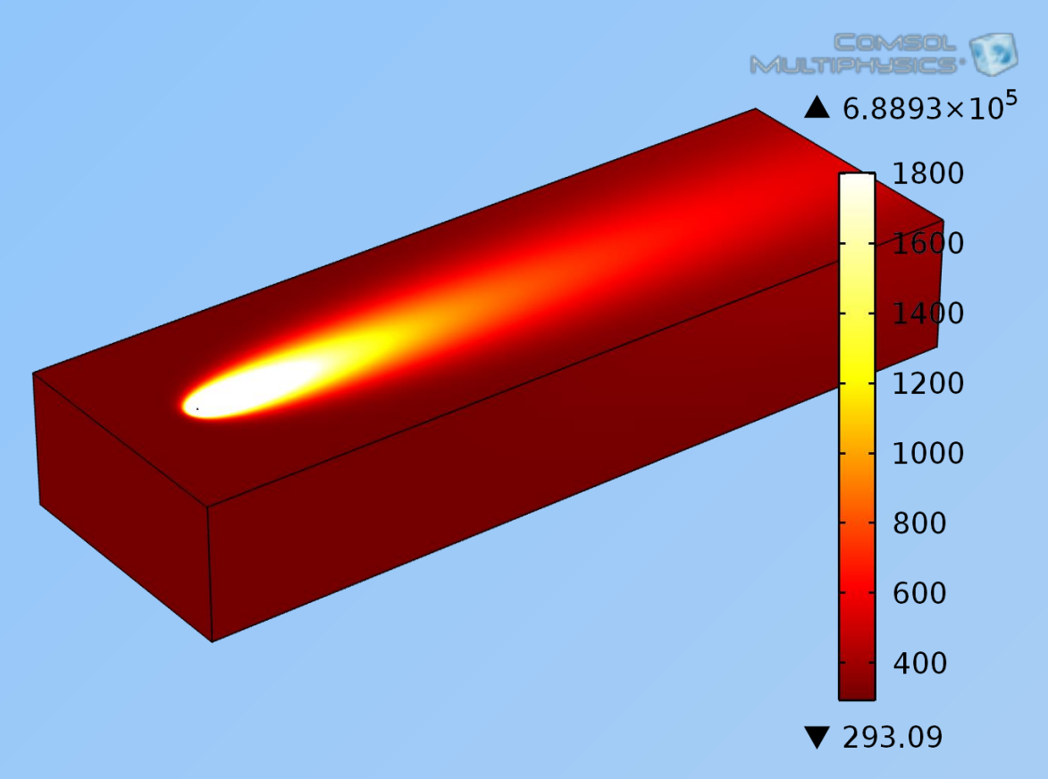

Figure 3a: Thermal profile. Source applied on a hemisphere.

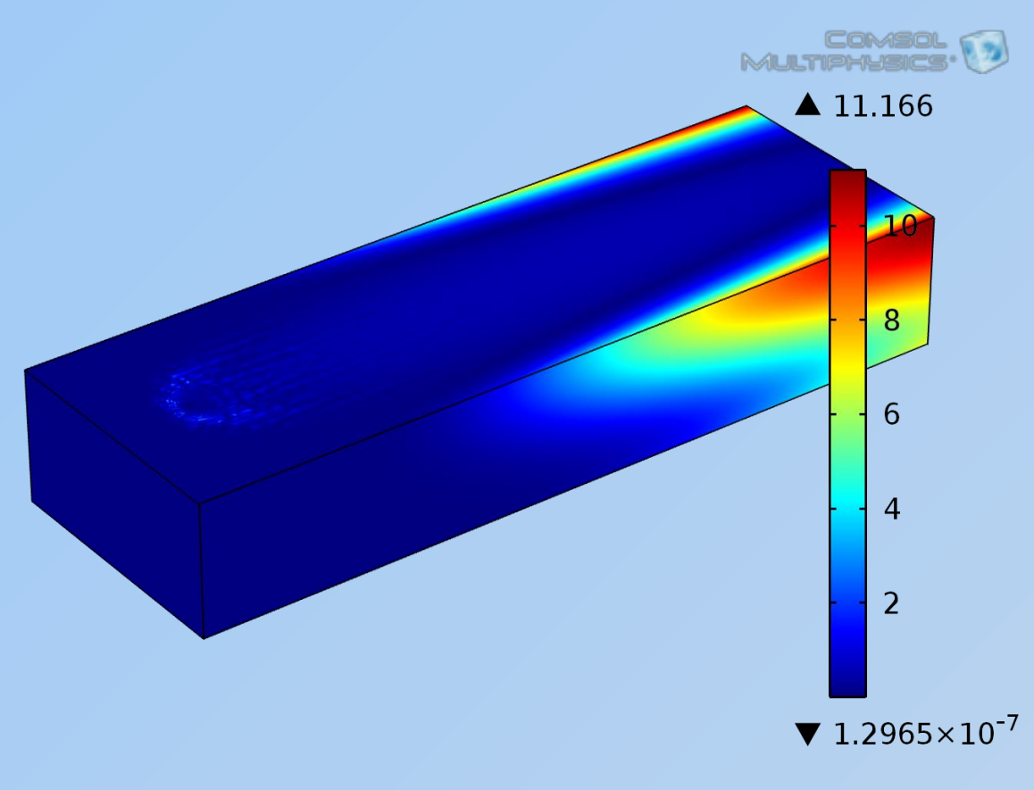

Figure 3b: Absolute relative difference with Rosenthal. Source applied on a hemisphere.

Hemisphere radius (m)	Maximum observed absolute relative error
$1x10^{-2}$	78.86%
$1x10^{-3}$	14.5%
$1x10^{-4}$	11.17% (Figure 3a)
$1x10^{-5}$	25.86%

Table 1: Maximum absolute relative error observed for several hemisphere radii.

Improvements due to the hemispherical source:

- The results are closer to Rosenthal (Figure 3a)
- No temperature below the initial one (Figure 3b)
- Easier post processing

Also the relevance of the use of a hemispherical source depends on its radius. Table 1 shows the evolution of the error when the radius of the hemisphere is changed.

Beyond Rosenthal

Variation of k and Cp with temperature

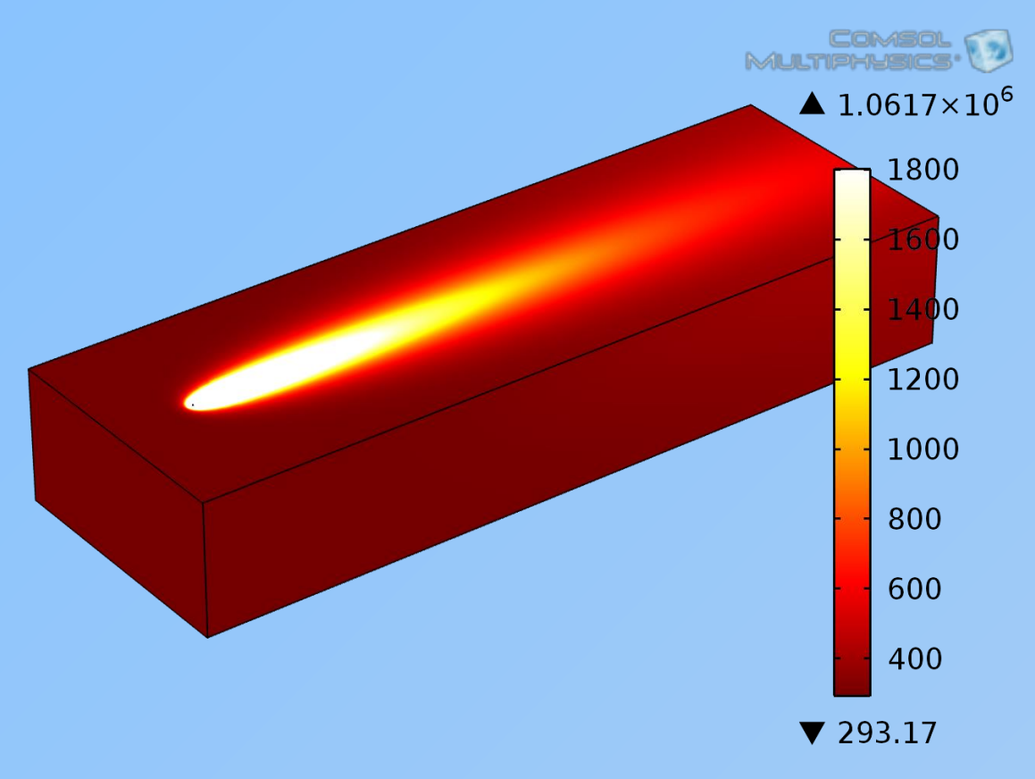

Figure 4a: Thermal profile. Source applied on a hemisphere. k and C_p are functions of temperature.

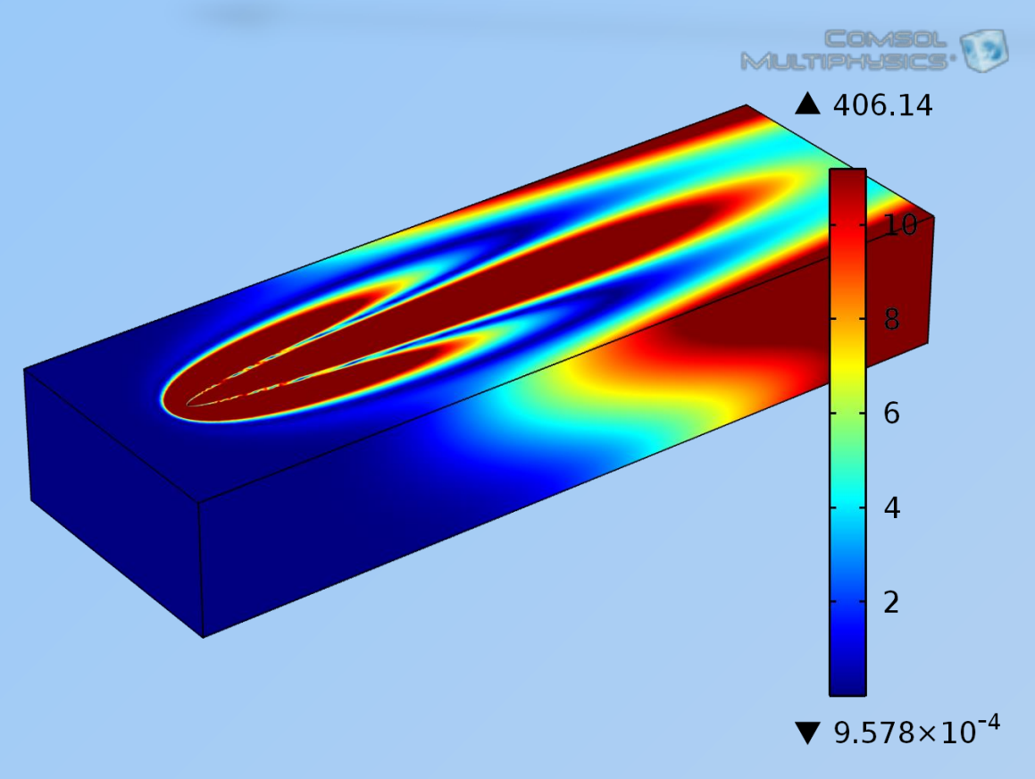

Figure 4b: Absolute relative difference with Rosenthal for k and C_p functions of the temperature. Same color scale as Figure 3b.

As a first approximation to take into account the variation of k and C_p with temperature, Equation 4 is used, but k and C_p are considered as functions of temperature.
Large discrepancies are observed compared with Rosenthal, which means that the variations in k and C_p with temperature have a significant effect on the thermal profile.
The data used come from the work of Nart and Celik [2].

Two sources

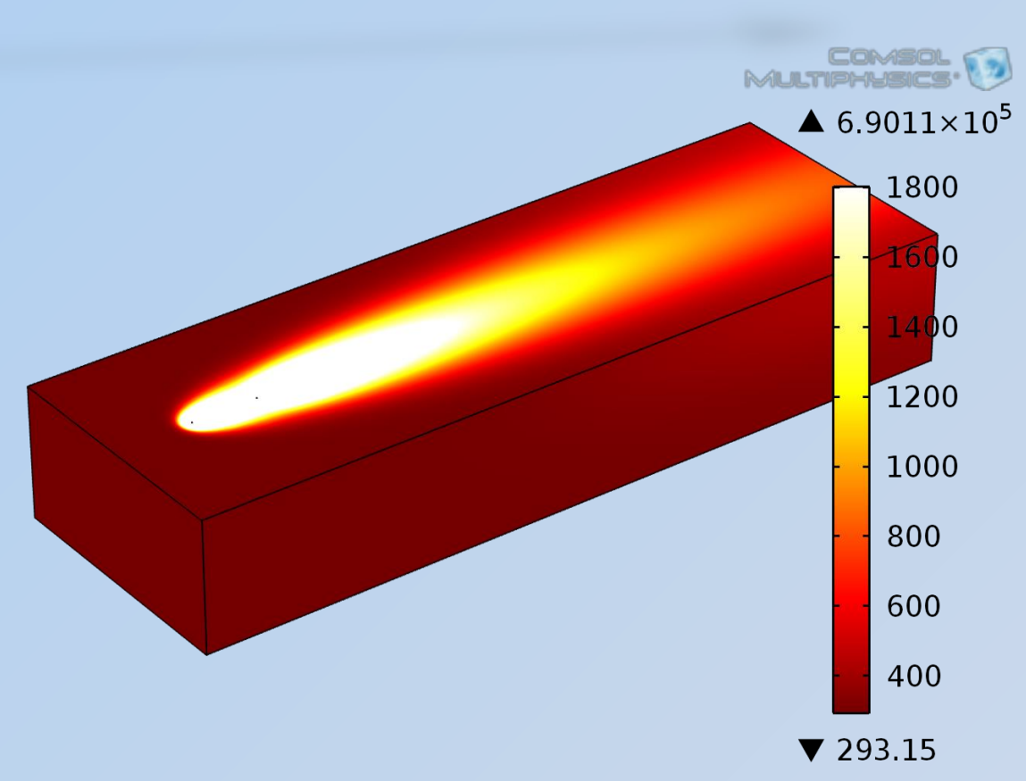

Figure 5a: Thermal profile. Two sources applied on a hemisphere. k and C_p kept constant.

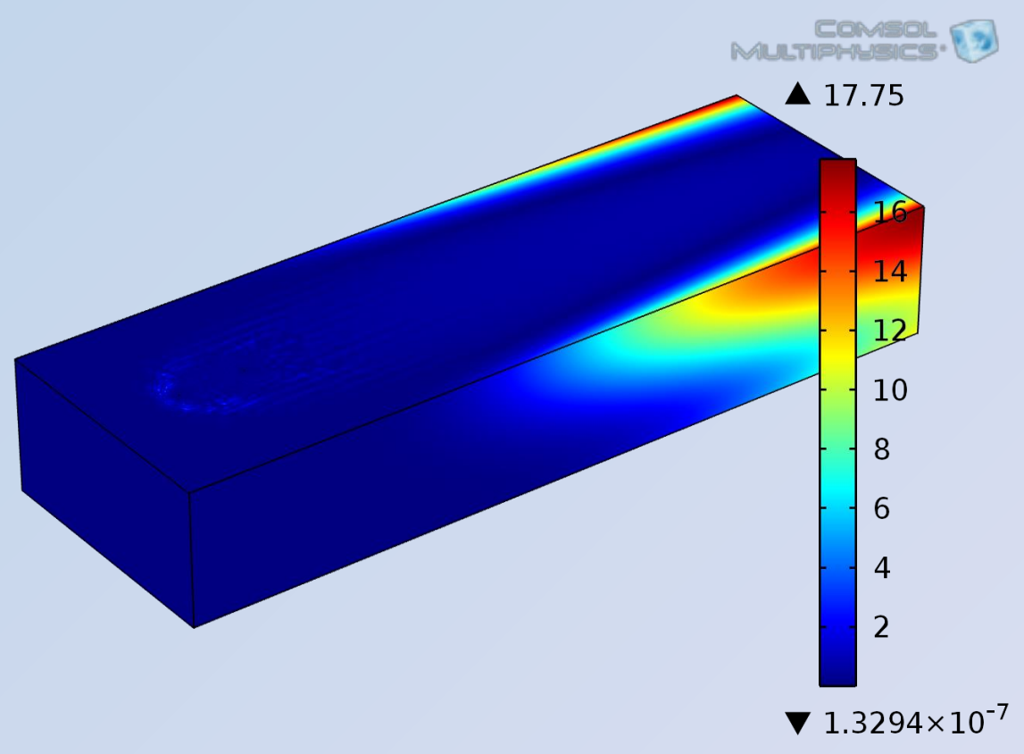

Figure 5b: Absolute relative difference with the analytical model. Two sources applied on a hemisphere. k and C_p are kept constant.

The difference between the numerical model and the superposition of two Rosenthal's solutions is bounded by 18%. Therefore the idea of superposing two Rosenthal's solutions seems valid. This still needs to be compared with experimental data.

Conclusions

- It is possible to reproduce Rosenthal's results accurately with COMSOL
- Applying the source on the surface of a hemisphere is the best way to do so
- Variations of k and C_p with temperature have a significant effect on the thermal profile
- A numerical and analytical way to simulate two sources welding have been proposed

Acknowledgements

The authors are grateful to the Natural Sciences and Engineering Research Council (NSERC) of Canada and to the following companies for providing research funding: Evraz Inc. NA, TansCanada Pipelines Ltd., Enbridge Pipelines Inc., UT quality Inc. and Alliance Pipeline Ltd. Valuable discussions with Dr. J. Mmbaga are also acknowledged.

References:
1. Rosenthal D., The theory of moving sources of heat and its application to metal treatments, *Trans A.S.M.E.*, **68**, 849-866 (1946)
2. Nart, E. and Celik, Y., A practical approach for simulating submerged arc welding process using FE method, *Journal Of Constructional Steel Research*, **84**, 62-71(2013)

Excerpt from the Proceedings of the 2014 COMSOL Conference in Boston