THERMAL CYCLES ANALYSIS DURING OXY- ACETYLENE FLAME AND AIR PLAZMA CUTTING

[1]František VYSOUDIL, [1]Vladislav OCHODEK, [2]Ondřej DIVIŠ, [1]Jiří BÍLEK

[1]*VSB - Technical University of Ostrava, Department of Mechanical Technology, Czech Republic, EU,* *frantisek.vysoudil.st@vsb.cz, vladislav.ochodek@vsb.cz, jiri.bilek.st@vsb.cz*

https://doi.org/10.37904/metal.2022.4479

Abstract

Material parts can be separated either mechanically or thermally. During the thermal cutting of the material, the base material is locally melted, burned, or vaporized. The different methods are distinguished by the heat sources that supply them with the necessary energy. The application of the different thermal cutting methods varies depending on the type of material to be cut, its thickness, the resulting desired cut quality, and the overall economic efficiency. This paper deals with the study of temperature cycles formed during thermal cutting of carbon steel of S355 type by oxy-acetylene flame thermal cutting and air plasma cutting. The obtained experimental data are used in the numerical simulation of the thermal cutting process by the given technologies.

Keywords Thermal cycles, thermal cutting, air plasma cutting, oxy-acetylene flame cutting

1. INTRODUCTION

Material cutting is a very important part of engineering production. Material parts can be separated either mechanically or thermally. During thermal cutting of the material, the base material is locally melted, burned or vaporized. The different methods are distinguished by the heat sources that supply them with the necessary energy [1,2]. The application of the different thermal cutting methods varies depending on the type of material to be cut, its thickness, the resulting desired cut quality and the overall economic efficiency. The thermal cutting operation usually precedes subsequent technologies such as forming, welding, surface treatment and therefore knowledge of its process significantly influences a wide range of engineering production [3-5]. The thermal cycle of thermal cutting is one of the fundamental characteristics of the process that are necessary for its optimization. Despite the widespread use of the given technologies in practice, real results on the thermal cycling during thermal cutting are rather sporadic [5-7]. When numerical simulations are used to optimize the process, the temperature cycle is the basic dependence to set up and verify the process [8-10]. This paper focuses on the two most widely used thermal cutting technologies, namely oxy-acetylene flame cutting and air plasma cutting.

2. THERMAL CYCLES MEASUREMENT DURING FLAME AND PLASMA THERMAL CUTTING

Any thermal separation of the material due to the action of the heat source results in a heat-affected area. In this area, there are structural and mechanical changes in the material, such as a change in structure, a change in grain size or a change in the hardness of the material. The size and shape of the heat-affected area depends on the amount of shape of the heat source and the heat introduced, which is predominantly affected by the cutting speed. The higher the cutting speed, the smaller the heat affected area and vice versa. In general, the smaller the heat affected area, the higher the hardness of the material in the cutting joint. For this reason, great emphasis is placed on the most accurate determination of the heat-affected area.

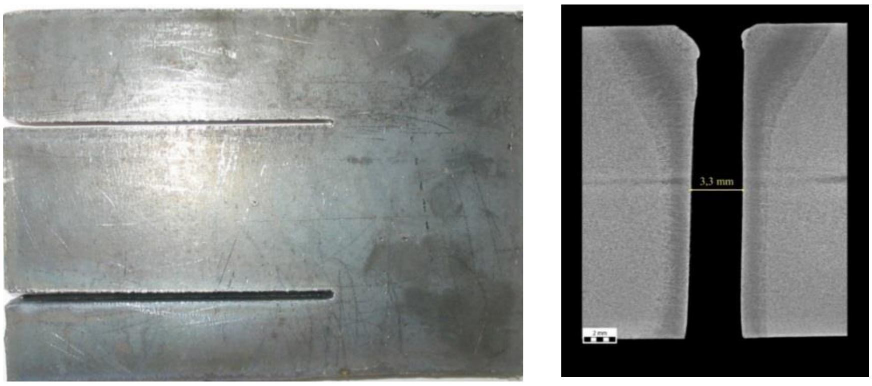

Figure 1 Comparison cuttings grooves, cutting grooves flame cutting

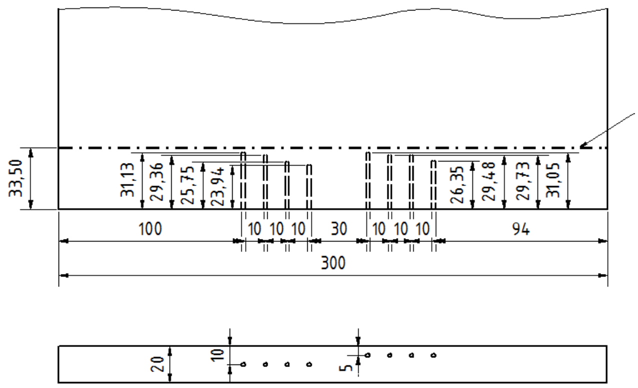

Figure 2 Geometry of the test section-plasma cutting

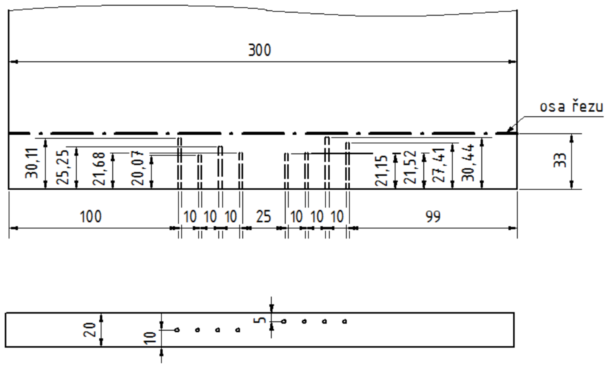

Figure 3 Geometry of the test section-flame cutting

Figure 1 shows a comparison of the cutting gaps of the different technologies. The upper cutting gap belongs to the plasma technology, where a cutting speed of 1800 mm/min was used. The lower cutting gap belongs to the oxygen technology, where a cutting speed of 324 mm/min was used. The thermal cutting parameters were verified on test specimens made of S355 structural non-alloy steel with dimensions 300 X 120 X 20 mm. Test cuts were then made on the specimens to determine the cutting gap (see **Figure 1**). For a given cutting technology, the cutting joint was determined by metallographic testing. After the cutting parameters were set, eight K-type thermocouples were placed in the specimens to measure the temperature in the area of the cut. Four thermocouples were placed at the mid-thickness of the sample and the remaining four were placed 5 mm from the sample surface as shown in **Figure 2** and **3**

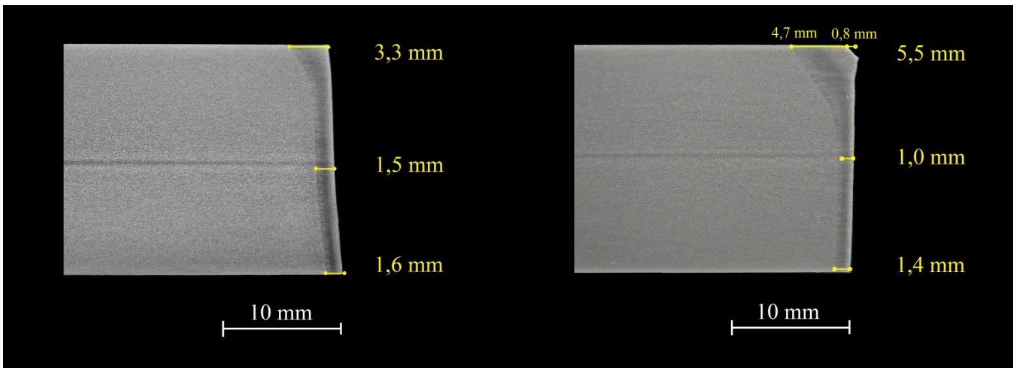

Figure 4 Metallography and geometry of cuttings grooves (plasma-left, flame-right)

Metallography and geometry of cuttings grooves for plasma and for flame shows **Figure 4**. The thermocouples were then used to continuously record data, which were processed into graphs and the maximum cycle temperature was determined. For flame cutting, the maximum temperature T_{max}=667 °C was measured for thermocouple T5 (see **Figure 5**). For plasma cutting, T_{max}=678°C was measured for thermocouple T5 (see **Figure 6**). The values of heating and cooling rates are given in **Table 1**.

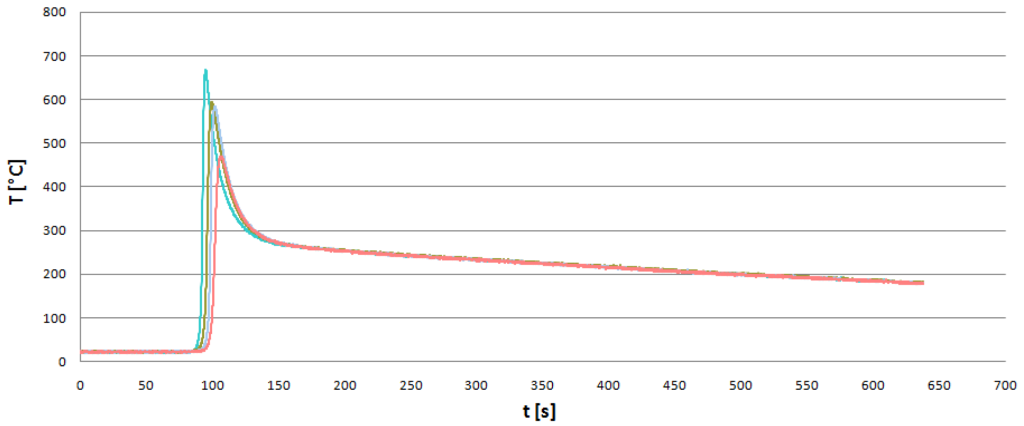

Figure 5 Temperature cycles under the surface of the material – cutting by flame

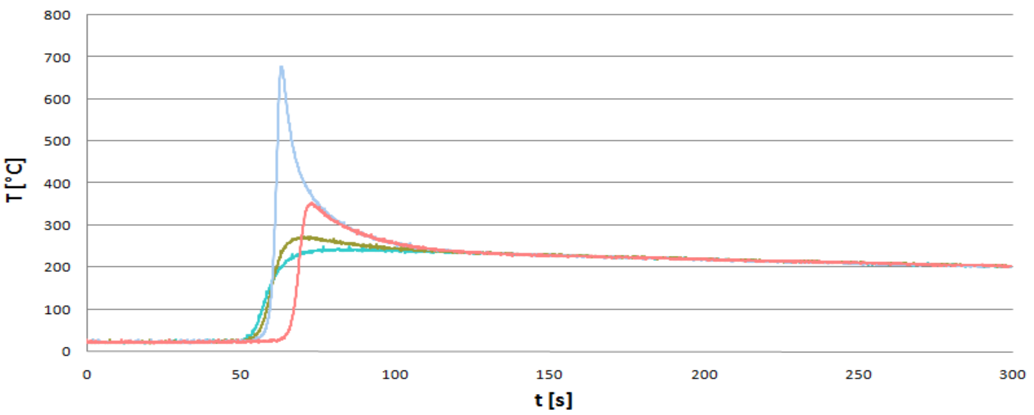

Figure 6 Temperature cycles under the surface of the material – cutting by plasma

Table 1 Values of heating and cooling rate for selected temperature cycles

	Heating rate (°C/s^1)	Cooling rate 1 (°C/s^1)	Cooling rate 2 (°C/s^1)
Flame – T5	198.40	8.21	0.18
Plasma – T2	192.22	12.72	0.24

The results of the measurements made, shown in **Figures 5** and **6,** are in good agreement with the authors [5,6]. Based on these results, it is possible to set the optimal boundary conditions for the numerical simulation of the process.

3. APPLICATION THERMAL CUTTING THERMAL CYCLES FOR FEM PROCESS SIMULATION

Experimentally measured temperature cycles allow realistic determination of boundary conditions for numerical simulation of the thermal cutting process and their verification. The advantages of virtual simulations of technological processes are presented in a number of papers. Simulations of thermal and mechanical processes during welding or heat treatment are difficult but quite extended. In the case of thermal cutting, the simulation is more complicated with respect to not only the thermal and mechanical

calculation but also the transport (removal) of mass from the cutting joint**. Figures 7-9** show the first results of the simulation of the thermal influence during cutting with an oxy-acetylene flame and plasma, which followed the experimental measurement of thermal cycles, see chap.2. Simufact Welding v. 2020 software was used for the FEM simulation. The advantages of numerical simulations are evident in the wide variability of the parameters and the significant limitations of experimental work.

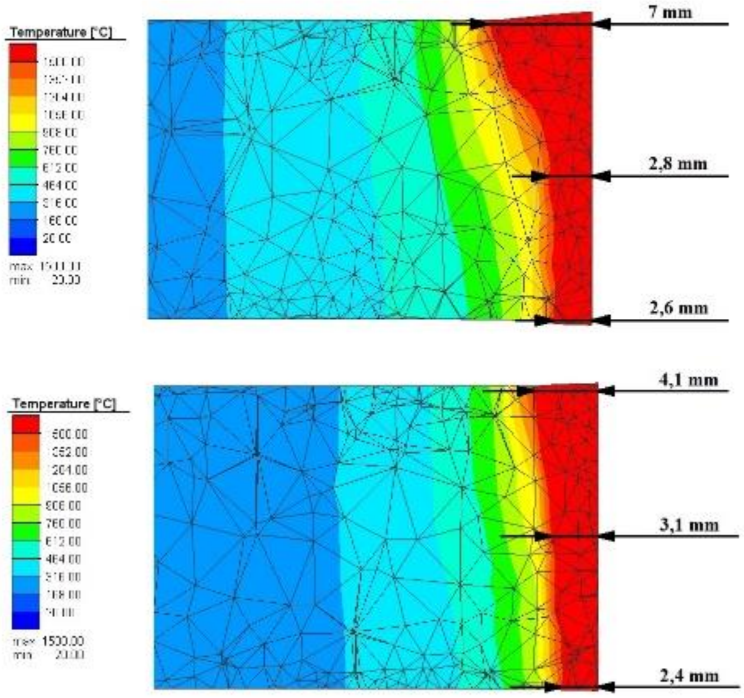

Figure 7 Thermal influence during FEM simulation of flame (above) and plasma cutting

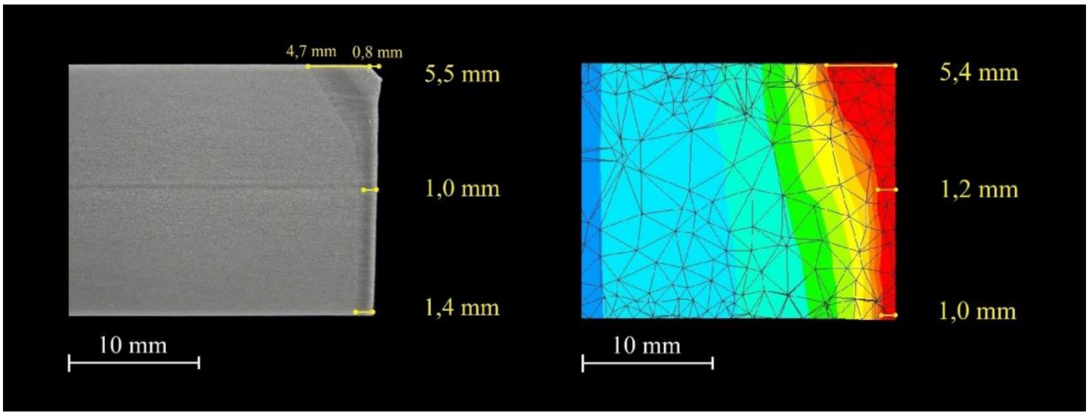

Figure 8 Comparison of thermal influence experiment and FEM simulation of flame cutting

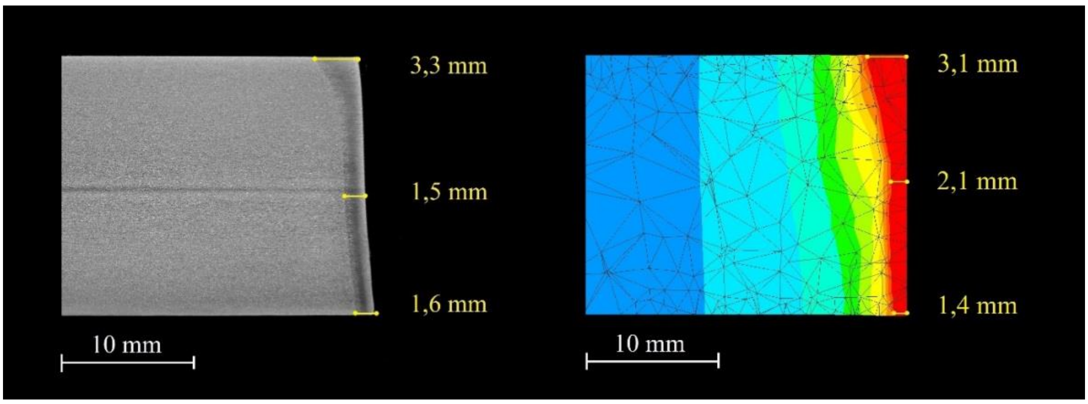

Figure 9 Comparison of thermal influence experiment and FEM simulation of plasma cutting

4. CONCLUSION

The paper presents the results of contact measurements of temperature cycles during thermal cutting by plasma and flame. Temperature cycles under the surface at the centre of the cut thickness were measured on unalloyed carbon steel. From the experimental cycles, the basic characteristics of the temperature cycles in the heating and cooling branches were determined. Based on the results obtained, it was possible to determine realistic boundary conditions for advanced numerical simulation in Simufact Welding v. 2020. The use of numerical simulation allows verification of a wide range of process parameters and their influence on the resulting properties without the need for extensive experimentation.

ACKNOWLEDGEMENTS

Results in the contribution were achieved at solving of specific research project No. SP2022/14 with the name of "Research and Development of Engineering Technologies and their Management" solved in year 2022 at the Faculty of Mechanical Engineering of VSB – Technical University of Ostrava.

REFERENCES

[1] HOULDCROFT, Peter Thomas, JOHN, Robert. *Welding and Cutting: A Guide to Fusion Welding and Associated Cutting Processes*. Woodhead Publishing, 2001.

[2] WEMAN, Klas. *Welding processes handbook*. Elsevier, 2011.

[3] ČADA, R. a LOŠÁK, P. Optimization of Bellows and Tubes Cutting by Disc Knife to Achieve the Minimum Burr Size. *Modern Machinery (MM) Science Journal*. 2021, vol. 14, no. 6, pp. 5373-5380. Print ISSN 1803-1269, Online ISSN (eISSN) 1805-0476.

[4] RUSZ, Stanislav, et al. Effect of severe plastic deformation on mechanical and fatigue behavior of medium-c sheet steel. *Journal of Mining and Metallurgy B: Metallurgy*, 2020, vol. 56, no. 2, pp. 161-170.

[5] OCHODEK, Vladislav, BOXAN, P. Weldability of carbon steel processed by multiple plastic deformation. *Archives of Materials Science and Engineering*. 2014, vol. 69, no. 2, pp. 88-93.

[6] TARABA, Bohumil, MARONEK, Milan, BABALOVA, Eva. *Experimental temperature measurement of oxy-acetylene cutting process*. Annals of DAAAM & Proceedings. 2010, pp.539-541.

[7] BAE, Kang-Yul, et al. Numerical analysis of heat flow in oxy-acetylene flame cutting of steel plate. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 2018, vol. 232, no. 4, pp. 742-751.

[8] SINGH, Dalvin, CHATTOPADHYAYA, Somnath. Temperature measurement in plasma cutting through infra-red imaging and comparison with FEM. *Manufacturing and Industrial Engineering*, 2014, vol. 13, pp. 3-4.

[9] LINDGREN, Lars-Erik, CARLESTAM, Alen, JONSSON, Mikael. Computational model of flame-cutting. 1993.

[10] ARENAS, Manuel J., et al. Modelling and simulation of flame cutting for steel plates with solid phases and melting. *Journal of Mathematics in Industry*. 2020, vol. 10, no. 1, pp. 1-16.