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EXPERIMENTAL MEASUREMENT AND NUMERICAL SIMULATION OF TEMPERATURE DURING DRILLING WITH FOUR SPECIFIC DENTAL DRILLS

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Abstract: *High temperature during bone drilling is not required. The aim of presented study was experimentally measure and simulate thermal diffusion differences in the surrounding of the two specific drills during hole drilling into the polyurethane (PUR) foam block (from Sawbones Europe AB). Polyurethane (PUR) block was ("artificial bone") with 6 holes in 5mm depth for semiconductor termoelements. Holes for thermocouple were distributed in perpendicular direction along the drilling direction. These thermocouples measure thermal diffusion in according to the drill depth into the PUR blocks. Experiment was performed with and without cooling and in three different revolution speeds, 800rpm, 3000rpm and 5000rpm. Experimental investigation was realized on four types of drills.*

1 INTRODUCTION

The aim of presented study was experimentally measure and numerical simulate thermal diffusion differences in the surrounding of the two specific drills during hole drilling into the polyurethane (PUR) foam block.

Firstly, heat is generated in the primary deformation zone due to plastic work done at the shear plane. The local heating in this zone results in very high temperatures, thus softening the material and allowing greater deformation. Secondly, heat is generated in the secondary deformation zone due to work done in deforming the chip and in overcoming the sliding friction at the tool-chip interface zone. Finally, the heat generated in the tertiary deformation zone, at the tool workpiece interface, is due to the work done to overcome friction, which occurs at the rubbing contact between the tool flank face and the newly machined surface of the workpiece. Heat generation and temperatures in the primary and secondary zones are highly dependent on the cutting conditions while heat generation in the tertiary zone is strongly influenced by tool flank wear [1] [2].

The factors that should be considered when choosing a temperature measurement method for a particular application are: temperature range; sensor robustness; temperature field disturbance by the sensor; signal type/sensitivity to noise; response time; and uncertainty. These should be weighed against the following criteria: ease of calibration; availability; cost; and size [3][4].

2 MATERIAL AND METHODS

Biomechanical test blocks also offer uniform and consistent physical properties that eliminate the variability encountered when testing with human cadaver bone. They're primarily used for testing orthopaedic implants, instruments and instrumentation.

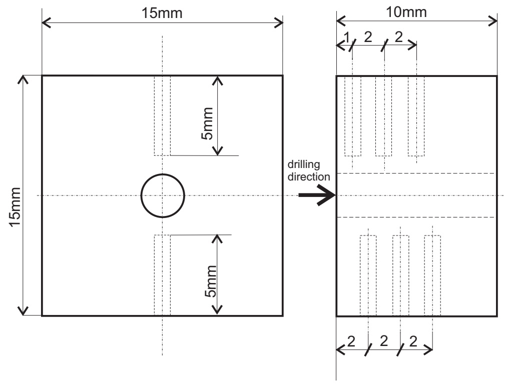

Figure 1.: PUR block with designed holes for Thermocouples in perpendicular direction to drilling direction.

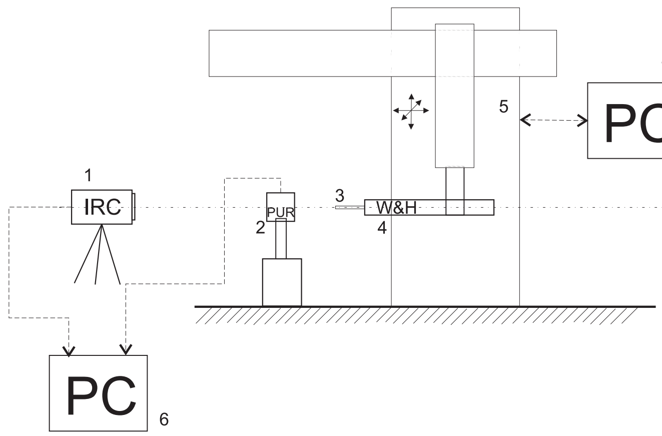

Figure 2.: Experimental setup: 1 - IR camera with conncetion to PC 2 - PUR block with installed thermocouples connection to PC; 3 - measured drill; 4 - W&H surgical drilling machine; 5 - drilling machine fixation and three axis movement; 6 and 7 - PC for drill movement controlling and recording data from IR camera and thermocouples.

In experimental measurements and FE analyzes was used PUR foam because it's primarily used as an alternative test medium for human cancellous bone. Polyurethane (PUR) block was ("artificial bone") $15x15x10mm$ with 6 holes in $5mm$ depth for semiconductor termoelements, see Figure 3.1. Holes for thermocouple were distributed in perpendicular direction along the drilling direction. These thermocouples measure thermal diffusion in according to the drill depth into the PUR block. Thermocouples were fixed into the PUR block with silver thermo paste for better temperature transmition between block material and thermocouple.

Experimental setup, Figure 2, consist of fixation the surgical drilling machine (W&H) in three axis movement CNC machine. A PUR block with installed thermocouples for detection temperature inside the block, was fixed in a table in the same horizontal axis as surgical drilling machine, and in drilling direction. In front of the PUR block was installed IR camera (FLIR) for recording the temperature in the cutting edge of experimental drills during perforating the PUR Block.

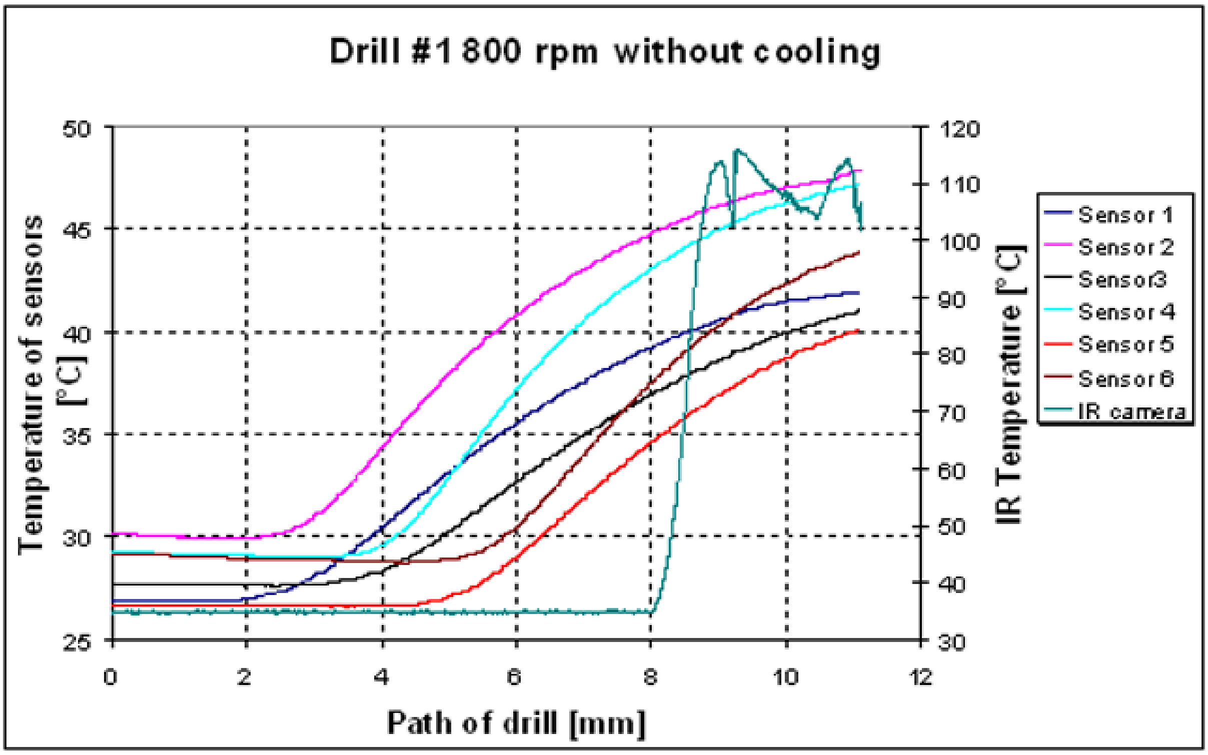

Figure 3.: Drilling without cooling - Drill 1610.928b with rotational velocity 800rpm. Sensor number is number of thermocouple.

Experiment was realized in three different rotational speeds 800, 3000 and 5000rpm. Every measurement combination of drill type and rpm was with and without cooling. For cooling, the surgical drilling machine cooling system was used. Cooling medium was water. Cooling water was applied by showering on the used drill. Axial movement of a drill was in all cases 30*mm/min*.

Experimental investigation was realized on four types of drills. Two cylindrical and two conical drills from two different manufacturers.

Aims of the FE simulation were heating analyzes of the drill and PUR foam during drilling. Heating was produced by the friction of the alloy drill on the PUR foam [5]. All analyzes were defined as the static, coupled thermal-displacement simulations with nonlinear contact definition.

Simulations were modeled as the nonlinear contact task, where contact was defined among hole surface and outer drill surfaces (see Figure 3). Contact formulation was normal hard contact, with friction coefficient dependent on temperature. Produced heating were distributed evenly to both parts. Initial temperature on the beginning of the numerical simulation in all parts was set to T=20°.

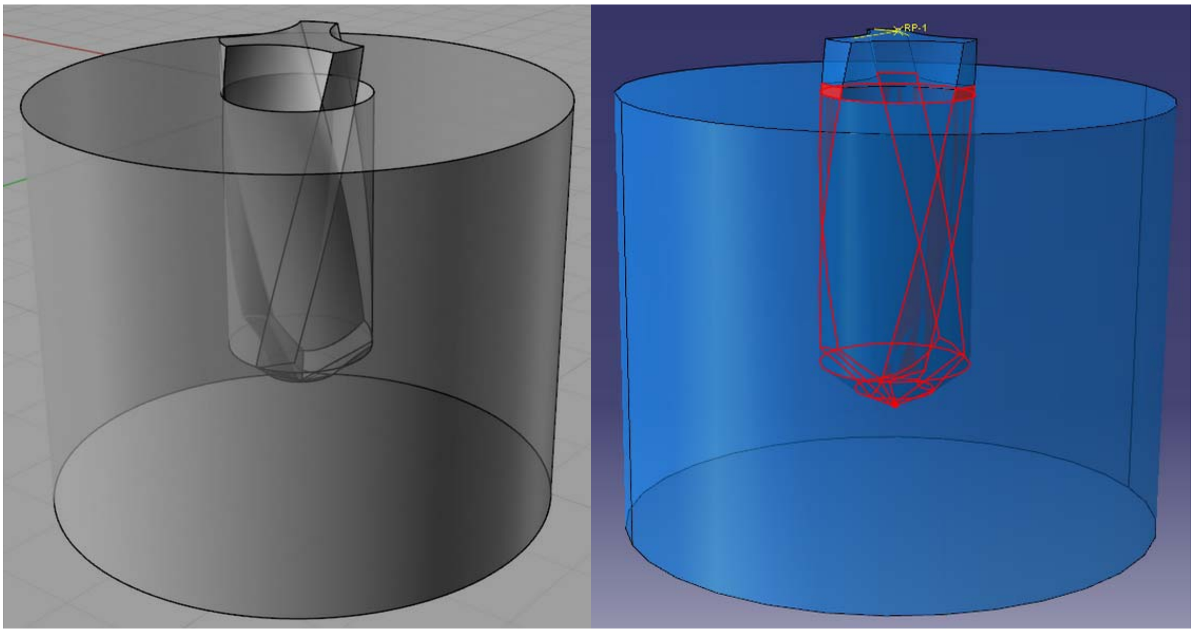

Figure 4.: Assembly and contact surfaces and reference point of the drill.

3 RESULTS AND DISCUSSION

From the experimental results can be said: Drill 1610.914d-k (conical Drill), can not be used in revolutions 800rpm together with axial movement 30*mm/min* in case with and without cooling. The drill stops. Measured temperatures for this drill are maximal in both cutting edge and in surrounding of drill.

At least heated was conical drill no. 1610.914d. It was detected in both experiments with and without cooling and in all revolution speeds. Maximum temperature was in surrounding of drill 50,7°*C* and at the cutting edge 94,74°*C*

In both cylindrical drills, no.1610.928b and no.1610.928b-k were detected very similar temperatures. In case with cooling were lower temperatures in drill no.1610.928b-k and in case without cooling were lower temperatures in drill no.1610.928b. In drill no.1610.928b was detected significantly highest temperature with revolution speed 5000rpm surrounding of drill in case without cooling. Diagrams of temperature influence on drill path is shown on Figure 3.

From performed drills FE analyzes were temperature T [◦C] distribution on drills and PUR foam cylinder obtained. Von Misses stress σ_{HMH} [MPa] distribution on drills were obtained as additional results. Summary of the analyzed results is shown in Table 1.

Table 1.: Table of results for drilling in PUR foam with revolution speed 800rpm .

Drill model	Temperature T [◦C] FE analyzes		Temperature T [◦C] Experiment	
	drill	PUR foam	cooling	no cooling
1610.928b	120.9	120.3	**94.46**	**115.36**
1610.928b-k	90.6	90.4	**62.95**	**84.43**
1610.914d	89.0	88.9	**57.45**	**77.16**
1610.914d-k	133.2	132.9	**150.21**	**180.30**

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5 ACKNOWLEDGEMENT

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