Drilling of bone: numerical and experimental investigations

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1. INTRODUCTION

Implant failures and post-operative problems may occur after implant placement as a result of the inappropriate conditions during drilling. The analysis of different materials and drilling parameters is crucial to reduce the bone damage and contribute to the success of this medical interventions.

Motivation: Contribute towards the application of optimum drilling parameters that will minimise the bone damage due invasive procedures.

Main objectives

- Study parameters (drill speed, feed-rate and drill bit diameter) on temperature strains and stress evolution, during drilling of synthetic bone, *ex vivo* bovine femurs and human cadaveric tibiae.

2. EXPERIMENTAL TESTS

- Experiments were performed using three different materials: polyurethane foams, bovine femurs and human cadaveric tibiae.
- All samples were instrumented with thermocouples and strain gauges to measure the temperature distribution and the strain level.
- Temperature control in the cutting tools were carried out using a thermal camera (1.5 m from the drilling area).
- Table 1 shows the list of parameters used in the experimental tests.

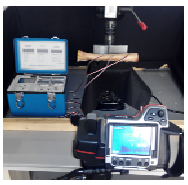


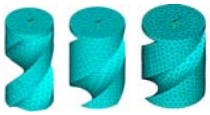
Table - 1 Parameters used in the drilling tests.

Parameters	
Drill diameter, mm	4, 5, 6 (mm)
Drill point angle	118°
Drill speed, rpm	520, 600, 800, 900, 1200, 1370
Feed-rate, mm/min	25, 50, 75

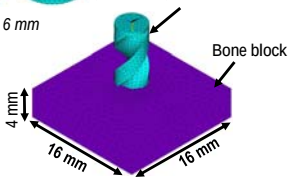
- All holes were carried out at room temperature without cooling.
- The holes were performed in a CNC machine (feed-rate controlled) and a vertical drilling machine (uncontrolled feed-rate).

3. NUMERICAL MODEL

- 3D dynamic numerical models were developed using ANSYS program.
- Finite element was 3D SOLID164. Mesh size discretization in the drilled zone and a coarse mesh in the remain block.
- Block model was modelled as plastic-kinematic hardening model (Cowper-Symonds) and drill bits as a rigid body.
- *CONTACT_ERODING_SURFACE_TO_SURFACE was used to simulate the contact between the drill bit and the block. Failure strain as material failure criterion was used to simulate the hole perforation.



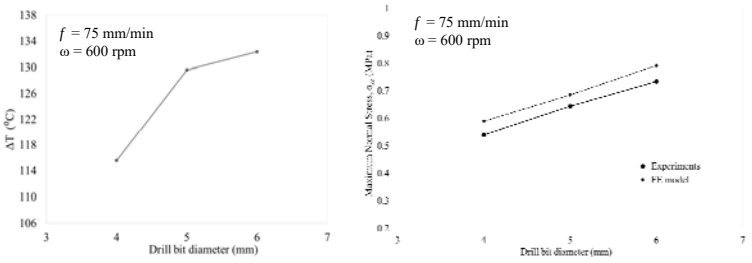
Drill bit Ø 4, 5, 6 mm



Properties	Block	Drill bit
Density (kg/m³)	800	7850
Young's Modulus, E (GPa)	0.987	200
Poisson's ratio	0.3	0.3
Initial Yield Stress, σ_0 (MPa)	22.59	
Tangent Modulus, E_p (MPa)	0.91	
Hardening Parameter, β	0.1	
Cowper-Symonds strain rate parameters:		
C	2.5	
P	7	
Failure Strain	0.05	
Friction coefficient	0.3	0.3

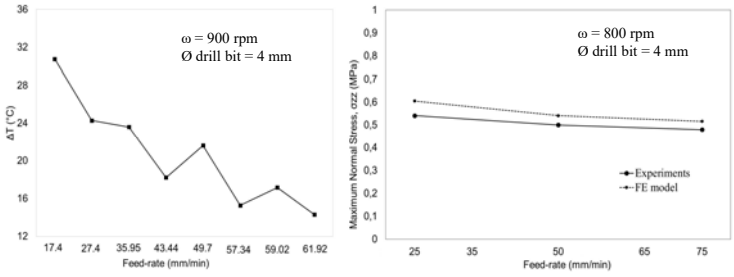
4. RESULTS AND DISCUSSION

Effect of drill diameter: Graph (a) displays the effect of drill bit diameter on temperature variation from experimental tests with polyurethane foams and the graph (b) shows the results comparison of FE models and experiments for the maximum normal Stress, σ_{zz} (Mpa).



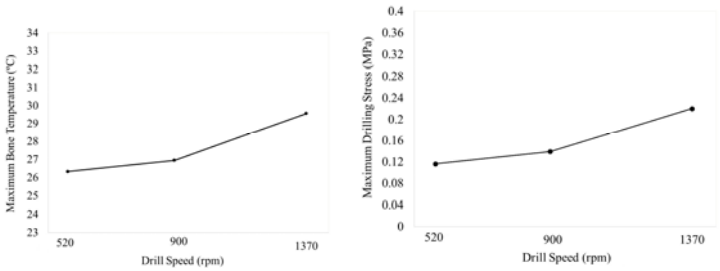
(a) (b)

Effect of feed-rate: Graph (a) displays the temperature variation on drill bit from experimental tests with bovine femurs and graph (b) shows the results comparison of FE models and experiments with polyurethane foams for the maximum normal Stress, σ_{zz} (Mpa).



(a) (b)

Effect of drill speed: Graph (a) displays the average of maximum bone temperature distribution inside of human cadaveric tibiae and graph (b) shows the average of maximum drilling stress distribution on surface of human cadaveric tibiae.



(a) (b)

- Results identified the drill bit diameter as the most critical parameter for inducing higher temperatures and stresses in bone drilling.
- The increase in drill speed and less feed-rate caused increase in bone temperature and stresses during drilling.
- Validation was carried out comparing numerical results and experiments and good accuracy was found.

5. CONCLUSIONS

- The present study showed that the combinations of appropriate drill parameters can reduce the generated temperatures and stresses during drilling.
- The proposed numerical models are a valuable tool for the health professionals and their patients.
- The findings of this survey complement previous research developed by our team [1-4].

[1] Fernandes et al. (2015, 2017) *Proc IMechE Part L: J Materials: Design and Applications;*
[2] Fernandes et al. (2016) *J Braz Soc Mech Sci Eng* 38:1855-1863;
[3] Fernandes et al. (2017) *J Mech Med Biol* 17(3):1750082-16;
[4] Fernandes M.G., et al. (2017) *Journal of Mechanical Engineering and Biomechanics* 1(6):135-141

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