The Study on Microwave-Drilling Technology for Solid State Materials

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Abstract

The microwave-drilling method for solid state materials is an effortless and essential drilling technology process that allows easy control and manages exploitation with high speeded fast penetration in increase of temperature level. Application of this method to underground mining and other technology sectors will bring considerable results. Thereafter theoretical and technological study has a substantial significance. Low vibrations occurred during the untouchable milling, drilling without blow as drilling with reduction of complication of milling. The drilling results are successful, the drilling cost is low, wide use of drilling in commercial services are significant properties

Keywords*: microwave, microwave- drilling technology, solid state materials, ultra high electro-magnetic microwave, boring, drilling penetration, power, frequency, granite, gulf*

1. Introduction

Ultra high electro-magnetic microwave is the microwave with length of 1мм-1м, frequency 300MHz-300GHz. In 1984 the experimental tool and application was designed in Technology Institute of Japan. Their study design of microwave resonance network output to microwave lead for 1 sq.m of granite brings effective results. It was designed as his frequency of 915 ± 25 Hz, wave length 30 cm, and power of 30 kW.

In 1993, as per USA Mining Agency research report, it was modified by installation of into Richmond–based 54kW powered AR-16 apparatus resulting in available use for commercial purpose. Boring equipment manufacturing gulf Technology Company produced high intensity microwave generator with 2.45GHz, 440.6Mpa for granite. This was introduced in mechanical engine. This technology is widely used to produce a broad range of parts in various industries. Unlike conventional machining technologies, where material is removed from plain solid blocks to obtain the desired part, additive manufacturing technologies produce the solid body layer by layer by cross section of the raw material.

Microwave drilling would provide low cost solutions for these applications. In this article we report experimental results of 'microwave drilling of materials used HFSS model' a possible developed technique. The experimental results verify the rapid heating effect, similarly to the theoretical model.

2. Scientific rationale of research

The result of comparative study of microwave drilling of solid state materials shows the drilling varies from drilling penetration abilities.

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Table 1. Sighted energy flow parameters

Symbol	Description
P_d	power density (W/m3)
f	microwave density (Hz)
ε_0	Electric constancy in vacuum environment (8.854×10-12F/m)
ε''	false negative electric constancy pertaining to Temperature
E_0^2	Electric intensity (V/m)

By experiment of microwave in solid materials faces, some portions of energy have been reflected, while remaining is absorbed. Therefore, reflected part of in sighted energy flow is R:

$$P_d = 2\pi f \varepsilon_0 \varepsilon'' E_0^2 \quad (1)$$

$$R = \left| \frac{\left[\frac{\mu' - j\mu''}{\varepsilon' - j\varepsilon''} \right]^{\frac{1}{2}} - 1}{\left[\frac{\mu' - j\mu''}{\varepsilon' - j\varepsilon''} \right]^{\frac{1}{2}} + 1} \right|^2 \quad (2)$$

If assuming the magnetic and dielectric loss is small the formula (2) will be presented as follows.

$$R = \left| \frac{\left[\frac{\mu'}{\varepsilon'} \right]^{\frac{1}{2}} - 1}{\left[\frac{\mu'}{\varepsilon'} \right]^{\frac{1}{2}} + 1} \right|^2 \quad (3)$$

The energy transmission is defined through comparison of penetrated energy into solid materials to the energy standard meaning of planned microwave.

$$T = 1 - R \quad (4)$$

The microwave switch off distance 1/α, absorption capacity 1/ε, ε relative dielectric constancy of solid material, α switch off constancy.

$$\frac{1}{\alpha} = \frac{7.83 \times 10^7}{f} \left| \frac{2}{\mu k' \sqrt{\tan\delta_e yan\delta_m - 1 + \sqrt{1 + \tan^2\delta_e + \tan^2\delta_m + \tan^2\delta_e + \tan^2\delta_m}}} \right|^{\frac{1}{2}} f_t \quad (5)$$

f - Microwave frequency, f_t - linear frequency of absorption of solid materials, μ solid material penetration character, k' dielectric constancy of solid material, $\tan\delta_e = \varepsilon''/\varepsilon'$ tangent dielectric loss, $\tan\delta_m = \mu''/\mu'$ tangent magnetic transmission loss.

There is need to formulate Maxwell electro-dynamic system equation for the environment of microwave drilling of solid materials experiment. The Maxwell electro-dynamic system equation is:

$$\left.\begin{aligned} rot\overline{H} &= \overline{J}_g + \varepsilon\frac{\partial\overline{E}}{\partial\tau} + \overline{J}_X \\ rot\overline{E} &= -\mu_a\frac{\partial\overline{H}}{\partial\tau} \\ div\overline{D} &= \rho \\ div\overline{B} &= 0 \end{aligned}\right\} \quad (6)$$

The physics meaning of Maxwell I equation is that the twirled magnetic condition derived by transfer and lateral circulation even more variable electrical current.

The physics meaning of Maxwell II equation is that the variable magnetic creates the twirled electrical condition. The physics meaning of Maxwell III equation is that the Gaussian law in differential state and the electric condition state could be determined at any position area. It is need to underline that this equation is effectual not only for static electric condition, even more for dynamic (variable) electric condition.

The intensity line of magnetic condition is always closed, so the magnetic stream flowing through closed surface is without difference. Therefore $div\overline{B} = 0$

3. HFSS modelling

HFSS (High Frequency Structure Simulator) - is the program designed by a soft Company and as a three-dimensional electro-magnetic wave modeling program. In comparison with other program, it has a high accuracy and high simulation speed and simple for operation and for network interface. Accordingly it is widely used in many researches linked to airplane, cosmonautics, electronics, and transmitter and communication equipment. For the study experiment we have selected relatively refined materials using relatively different microwave drilling and observed the changes of demonstration of thermal effect. The modeling was made on use of the microwave generator with 2kW of power, 2.45GHz of frequency. Aluminum oxide refined material is used and parameters are shown in below table.

Table 2. Aluminum oxide parameters

	(Alumina)
Relative electric constancy	9.2
Relative magnetic transfer	1
Electric transfer	0
Dielectric loss angle	0.008
Magnetic loss angle	0
G- factor	2
Density	3720kg/m3

The microwave drilling is defined by copper material transmitter and symmetrical geometrical wave lead:

Table 3. Coaxial wave lead geometrical parameters.

Inner radius (mm)	**Outer radius (mm)**	**Wave lead length (mm)**
2	10	80

The microwave drill and its simulation could be further developed for other applications as well, including local heating and sensing, joining, pin insertion, and cutting in a variety of hard and soft materials. The proposed model used for microwave experimentation for drilling hole is shown in Figure 1.

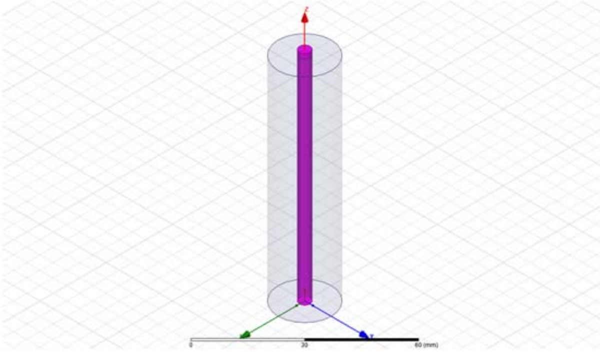

Figure 1. Microwave HFSS model

The proposed model has component as electromagnetic zone, magnetic induction, supporting work platform and the drilling zone are shown in Figure 2.

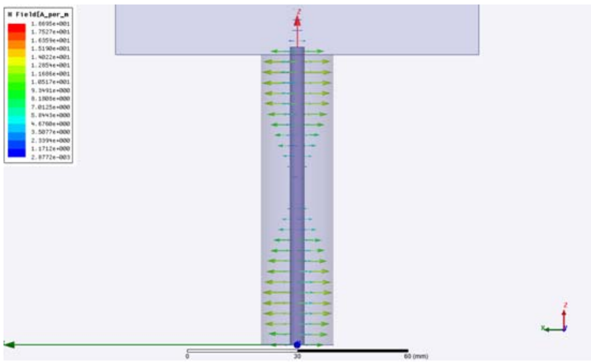

Figure 2. Electric Intensity vector at the YZ flat (a) zone propagation (b) Drilling beak propagation

Further results related to these figures are needed, including numerical analyses of the microwave-drill operation in materials, experimental simulation of microwave drills in various materials and conditions in comparison with theory.

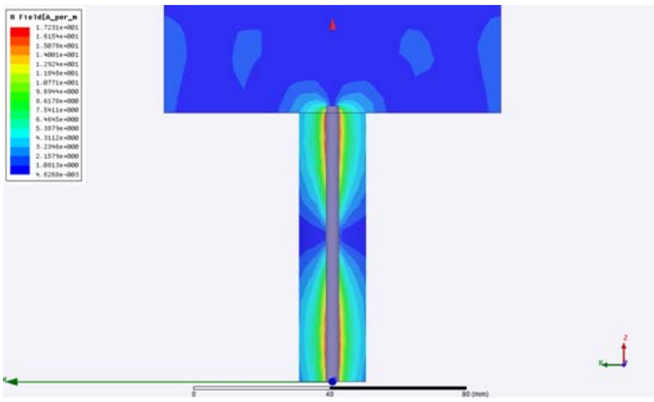

Figure 3. Distribution of electric intensity at the YZ flat (a) zone propagation (b) drilling beak propagation

The analysis of the microwave-drill mechanism couples the electromagnetic (EM) waves and their consequent thermal effects. The theoretical study of microwave drilling was done based on formulation of thermal effect from the Maxwell dynamic equation.

$$\frac{\partial E_r}{\partial t} = -\frac{1}{\varepsilon_0 \varepsilon'}\left(\frac{\partial H_\varphi}{\partial z} + \sigma_d E_r\right) \quad (7)$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon_0 \varepsilon'}\left[\frac{1}{r}\frac{\partial}{\partial r}(rH_\varphi) - \sigma_d E_z\right] \quad (8)$$

$$\frac{\partial H_\varphi}{\partial t} = \frac{1}{\mu_0}\left(\frac{\partial E_z}{\partial r} - \frac{\partial E_r}{\partial z}\right) \quad (9)$$

$$\sigma_d = \omega_0 \varepsilon_0 \varepsilon'' \;,\; \varepsilon = \varepsilon_0(\varepsilon' - \mathrm{j}\varepsilon'') \;,\; P_d = \omega_0 \varepsilon_0 \varepsilon'' \left\langle |E|^2 \right\rangle \quad (10)$$

$$\rho_m c_m \frac{\partial T}{\partial t} = k_t\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\partial^2 T}{\partial z^2}\right] + \frac{dk_t}{dT}\left[\left(\frac{\partial T}{\partial r}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right] + P_d \quad (11)$$

ρ_m - Material density , c_m - material thermal capacity , k_t material thermal transfer, T – temperature and sphere change moment)

$$\rho_m = \rho_m(T) \;,\; c_m = c_m(T) \;,\; k_t = k_t(T) \quad (12)$$

$$P_d = \omega_0 \varepsilon_0 \varepsilon'' \left\langle |E|^2 \right\rangle = 2.45 \times 10^9 \times 8.\ 854187817 \times 10^{-12}\,\mathrm{F/m} \times 0.0736 \times (3.54 \times 10^3\,\mathrm{V/m})^2$$
$$= 1.9003 \times 10^4\,\mathrm{J/m^3} \quad (13)$$

Looking from this, it is differing of high emission from microwave. The characteristic defiance, wave length and multiplier could be calculated from geometric parameters of coaxial wave lead:

$$Z_c = (2\pi)^{-1} Z_0 \ln(b/a) = (2\pi)^{-1}\sqrt{\mu_0/\varepsilon_0}\,\ln(b/a)$$
$$= \frac{1}{2\pi}\sqrt{\frac{4\pi \times 10^{-7}\,\mathrm{N/A^2}}{8.854187817 \times 10^{-12}\,\mathrm{F/m}}}\ln\frac{10}{2}$$
$$= 96.5\Omega \quad (14)$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\,\mathrm{m/s}}{2.45 \times 10^9\,\mathrm{Hz}} = 0.122\mathrm{m} \quad (15)$$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.122} = 51.3\mathrm{m}^{-1} \quad (16)$$

Aluminum oxide switches off and number of waves will calculated as:

$$\alpha = k\sqrt{\frac{\left(\sqrt{1+x^2} - 1\right)\varepsilon'}{2}} = 51.3 \times \sqrt{\frac{\left(\sqrt{1+0.008^2} - 1\right) \times 9.2}{2}} = 0.623 \quad (17)$$

$$\beta = k\sqrt{\frac{\left(\sqrt{1+x^2} + 1\right)\varepsilon'}{2}} = 51.3 \times \sqrt{\frac{\left(\sqrt{1+0.008^2} + 1\right) \times 9.2}{2}} = 155.6 \quad (18)$$

Antenna equivalent coefficient

$$L_{eq} \approx \beta h\left\{1 + \frac{0.19}{\ln(h/a) - 0.81}\right\} = 155.6 \times 0.002 \times \left[1 + \frac{0.19}{\ln(1) - 0.81}\right] = 0.238 \quad (19)$$

Free space medium characteristic defiance:

$$K_a = 60 \times \left[\ln\left(\frac{h}{a}\right) - 1 \right] = 60 \times [\ln(1) - 1] = -60 \tag{20}$$

Defining the coefficient of A and B:

$$A = \tan h\left[\left(\frac{\alpha}{\beta}\right) L_{eq}\right] = \tan 0.002 \times \left[\left(\frac{0.623}{155.6}\right) \times 0.238\right] = 1.9 \times 10^{-6} \tag{21}$$

$$B = \tan L_{eq} = \tan 0.238 = 0.243 \tag{22}$$

Radiation and absorption defiance will calculated as follows:

$$\begin{aligned} R_{\text{Rad}} &\approx 10 \frac{k}{\beta} L_{\text{eq}}^2 \left\{ 1 + 0.133 \times \left[1 - \left(\frac{\alpha}{\beta}\right)^2 \right] L_{\text{eq}}^2 + 0.02 \times \left[1 - 6\left(\frac{\alpha}{\beta}\right)^2 + \left(\frac{\alpha}{\beta}\right)^4 \right] L_{\text{eq}}^4 \right\} \\ &= 10 \times \frac{51.3}{155.6} \times 0.238^2 \times \left\{ 1 + 0.133 \times \left[1 - \left(\frac{0.623}{155.3}\right)^2 \right] \times 0.238^2 + \right. \\ &\quad \left. 0.02 \times \left[1 - 6\left(\frac{0.623}{155.3}\right)^2 + \left(\frac{0.623}{155.3}\right)^4 \right] \times 0.238^4 \right\} \\ &= 0.188 \end{aligned} \tag{23}$$

$$\begin{aligned} R_{\text{Heat}} &= \frac{k}{\beta} \frac{K_a}{1 + \left(\frac{\alpha}{\beta}\right)^2} \frac{A(1+B^2) + \frac{\alpha}{\beta} B(1-A^2)}{A^2 + B^2} \\ &= \frac{51.3}{155.6} \times \frac{-60}{1 + \left(\frac{0.623}{155.3}\right)^2} \times \frac{1.9 \times 10^{-6} \times (1 + 0.243^2) + \frac{0.623}{155.3} \times 0.243 \times (1 - 1.9^2 \times 10^{-12})}{1.9^2 \times 10^{-12} + 0.243^2} \\ &= -0.326 \end{aligned} \tag{24}$$

$$R_D = R_{\text{Rad}} + R_{\text{Heat}} = 0.188 - 0.326 = -0.138 \tag{25}$$

$$\begin{aligned} X_D &= \frac{k}{\beta} \frac{K_a}{1 + \left(\frac{\alpha}{\beta}\right)^2} \frac{\frac{\alpha}{\beta} A(1+B^2) - B(1-A^2)}{A^2 + B^2} \\ &= \frac{51.3}{155.6} \times \frac{-60}{1 + \left(\frac{0.623}{155.3}\right)^2} \times \frac{\frac{0.623}{155.3} \times 1.9 \times 10^{-6} \times (1 + 0.243^2) - 0.243 \times (1 - 1.9^2 \times 10^{-12})}{1.9^2 \times 10^{-12} + 0.243^2} \\ &= 81.4 \end{aligned} \tag{26}$$

4. Conclusion

Developing of methodology for theoretical calculation, and experiment modeling by HFSS program resulted in provision of availability of conducting experiment in all kind of materials. Using the high thermal effects derived from microwave wave lead allows to develop a drilling technology of solid materials and to make calculation. Low vibrations occurred during the untouchable milling, drilling without blow as drilling with reduction of complication of milling. The drilling results are successful, the drilling cost is low, wide use of drilling in commercial services are significant properties.

5. References

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