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Research Paper

PERFORMANCE OF DIFFERENT DRILL BITS IN MICROWAVE ASSISTED DRILLING

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This paper highlights on the drilling characteristics of various drill bits while drilling a microwave (MW) transparent material in a customized MW applicator. An attempt was made to investigate the feasibility of drill bit of different microwave reflective materials in a 2.45 GHz microwave applicator. The behavior of electrically conductive material was found to be more suitable as a drill bit for microwave drilling. Seven different types of drill bit were used while drilling hole in perspex work material. The test were performed in controlled atmosphere of domestic microwave applicator for less than 300 s. Observations could help while selecting a suitable drill bit with suitable size, shape and material for microwave drilling applications.

Keywords: Microwave drilling, Drill bits, Perspex, Applicator

INTRODUCTION

Drilling process has evolved through various changes till date. The changes were observed from conventional to non-conventional methods. Non-conventional methods are mostly preferred for drilling of difficult-to-machine-materials. These methods include Electric Discharge Machining (EDM), electrochemical machining (ECM), laser drilling and in the recent time microwave drilling. Various enhancements in microwave drilling processes have been endeavored by different researchers since initial success in microwave drilling was first reported by Jerby and Dikhtiar in the year 2000 (Jerby and Dikhtiar, 2000; Grosglik *et al.*, 2002; Jerby and Thompson, 2004; Jerby *et al.*, 2004; and George *et al.*, 2012). In addition to these enhancements, the time required to produce these holes is also an essential parameter of importance today. In an attempt to find an alternative to laser drilling, the feasibility of microwave drilling is being studied. Microwaves are used for processing of characteristically different materials [6-8]. Microwave interactions with these materials are also significantly different adding to its unique advantages and disadvantages. Proper understanding of microwave related concepts such as material loss factor, thermal

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runaway, hot spot, skin depth, selective heating, hybrid heating, etc., is yet to be achieved.

The process of microwave drilling was initially presented through a patent. In about four years the microwave drilling technology has been developed to suite different other applications like nailing, metal protecting as in Thermal Barrier Coating (TBC), cavity cleaning, material spectroscopy etc. Various research gaps in microwave drilling have already been addressed and few are in progress. One such study includes assessing behavior of various drill bit materials while drilling perspex. However, most of the works are concerned with drilling microwave absorbing materials such as concrete, ceramics and stone.

The present paper attempts to investigate the performance of microwave drilling process with various drill bit by varying its composition and morphology. The main objective of the study is to identify the best drill bit among the available options.

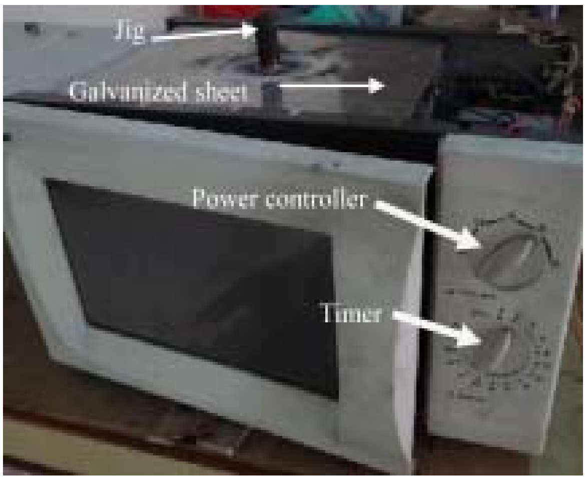
MICROWAVE APPLICATOR CUSTOMIZATION

In the present study, a MW applicator was used. The design customization of microwave applicator refers to modification in domestic microwave applicator. As shown in figure 1, the customization includes modifications on the top surface of the applicator. A cylindrical jig for guiding the drill bit was attached. The inner and outer diameters of the jig were 15.5 mm and 19.1 mm respectively and the length was of 9.7 mm. As the drill bits are fed on the work material by gravity, the jig plays a crucial role in addition to maintaining proper alignment. The microwave applicator (model HR-1770M of Haier make) has a capacity of 17 liter with microwave applicator volume of 285 x 277 x 182 mm. Since the microwaves in the applicator are sine waves, placing work material at proper location is critical. There is no rotary movement either on work material or on drill bit. This helps in concentrating microwaves on a point than distributing it over a surface or volume. The only movement permitted was vertical translatory movement of drill bit over the work material.

The work material chosen was Poly Methyl Methaacrylate (PMMA), commonly known as perspex. The work material was uniformly cut into specimens of cross section 30 x 12 x 11 mm, for effective handling and uniformity. Microwaves should interact with drill bit material to generate heat above the melting point (160 °C) of work material in order to get a hole drilled on it.

The controlling parameters in the customized setup are power setting, time of drilling and drill bit entry. In order to understand

Figure 1: Customized Microwave Drilling Setup

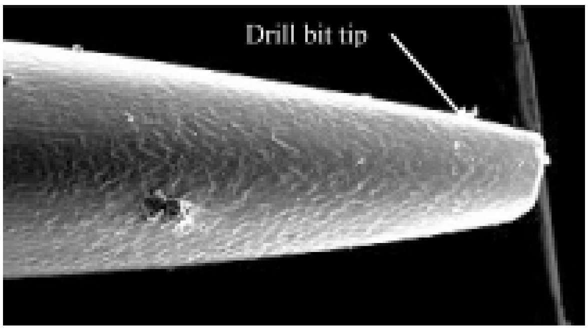


the morphology and material interaction all three controlling parameters were kept constant. The power setting was kept at 700 W and time for drilling was for 180 s. Work supporting platform height was also fixed and drill bit entry was chosen from top as suggested in literature. Microwaves in the customized applicator are operated at 2.45 GHz, as recommended by Federal Communication Commission (FCC) for Industry, Scientific and Medical (ISM) (Metaxas, 1996).

DEVELOPMENT OF DRILL BITS

In conventional drilling, the role of drill bit is very crucial. Most of the drilling improvements are in the form of proper design and selection of drill bit parameters. In some of the non-conventional drilling processes like laser drilling, electron beam drilling drill bits are never used. The mutually perpendicular electromagnetic waves do not allow energy to get focused directly on the work material for drilling a hole. A drill bit is therefore primarily used as a concentrator of microwave energy. Drill bits are made of characteristically microwave reflective material. The most common microwave reflective materials are steel and copper which were selected for the present study. A typical tool at 100 X magnification is shown in Figure 2. It shows the morphology of a tapered tool of about Φ200 μm tip. Length of tool is varied to impart self weight on the perspex work material with gravity feed.

Figure 2: Drill Bit Morphology at 100 X



Seven types of drill bit were selected for the study. The first (Type-I) and second type (Type-II) of drill bits are of steel and copper, brazed on a drill holder as shown in Figure 3. These drill holders add extra self weight on work material and also helps in proper alignment of the drill bit inside the customized jig placed over the microwave applicator. The drill holder is made to fit inside the jig and corresponds to hexagonal cross section inscribed in the diameter of 15 mm. The jig is also having step diameter of 7.35 mm helical groove to reduce weight and neutralize the microwaves coming

Figure 3: Brazed Drill Bit of (a) Type-I and (b) Type-II

out from the cylindrical jig. The copper tool is of 25 mm length with a diameter of 1.4 mm and self weight of 0.327 g, while steel tool is of 40 mm length, 0.84 mm diameter and self weight 0.361 g. The self weight of drill holder with steel tool and copper tool is 20.719 g and 21.185 g respectively. Length of drill holder is 55.4 mm and its major and minor diameters are 15 mm and 7.35 mm respectively. All the weight measurements were carried out using a Shimadzu AUW220D weighing machine with an error of 1 mg.

Some other drill bits selected for the study are shown in Figure 4. The third (Type-III), fourth (Type-IV) and fifth (Type-V) drill bit selected for the study are steel helical groove, mild steel flux coated and tapered copper drill bit respectively. The grooved steel bit is typical conventional drill bit of length 64.3 mm, point length of 1.56 mm and diameter of 3.0 mm with a self weight of 2.975 g. The fluxed mild steel bit is of length 165 mm, cone length of 0.8 mm and diameter of 2.3 mm (without flux) and 3.0 mm (with flux) bearing a self weight of 4.56 g. The tapered copper drill bit is made in two different lengths of 45.8 mm and 90 mm, with self weight of 16.762 g and 32.5 g respectively. The relatively lighter weight bit has a point length of 32.34 mm as compared to the heavy weight point length of 16.76 mm.

Figure 4: (a) Steel Grooved (Type-III), (b) Mild Steel Coated (Type-IV), and (c) Copper Tapered (Shorter Length: Type-Va, Longer Length: Type-Vb) Drill Bits

The seventh (Type-VI) drill used was of Litz wire (copper) as shown in Figure 5. The Litz wire bit has the self weight of 11.497 g with dielectric coating, overall length of 15.8 mm with white polymer dielectric coating over it. It has seven strands of copper wire each of diameter 0.6 mm and overall cross section diameter of 2.1 mm. Since these bits are having sufficient dimensions and self weight, they were fed inside the applicator without drill holder. The details of all seven types of drill bit selected are summarized in Table 1.

EXPERIMENTAL RESULTS

Different set of experiments were performed to establish the feasibility of particular drill bit material and morphology for perspex work material. For different investigations seven type

Figure 5: Litz Wire Drill Bit

Table 1: Different Drill Bits Selected for Microwave Drilling

Type	Mat.	Weight (g)	Length (mm)	Dia (mm)
I	Thin steel	0.361 (20.719*)	40	0.84
II	Thin copper	0.327 (21.185*)	25	1.4
III	Grooved steel	2.975	64.37	3.0
IV	Flux coated mild steel	4.566	165	2.3 (3.0#)
Va	Short tapered copper	16.762	45.8 (16.76$)	1.05 to 8.03
Vb	Long tapered copper	32.506	90 (32.34$)	0.86 to 8.03
VI	Litz copper	11.497	15.8	2.1 (7.3#)

Note: * Tool material weight with brazed drill holder; $ Point length of tapered drill bit; # Outer diameter with coating.

of drill bits were varied to understand microwave drilling phenomenon on work material. The power level of 700 W and time of interaction of microwave energy in the customized setup was maintained at 300 s. Each experiment was performed twice.

The hole drilled by drill bit of Type-I with microwave energy in the customized setup is shown in Figure 6. The hole so drilled on perspex work material was of diameter 1.6 mm to a small depth of 3 mm. The hole diameter obtained was 90.4% more than that of the drill bit diameter used. In some of the cases, the work material was burning. The holes were found surrounded with porous ejected material protruded out of the hole as shown in Figure 7. The Energy Dispersive Spectroscopy (EDS) as presented in Table 2 further confirmed traces of Cr and Fe. This clearly shows that some amount of drill bit wear was taking place while drilling.

Figure 6: Hole Drilled with Type-I Drill Bit

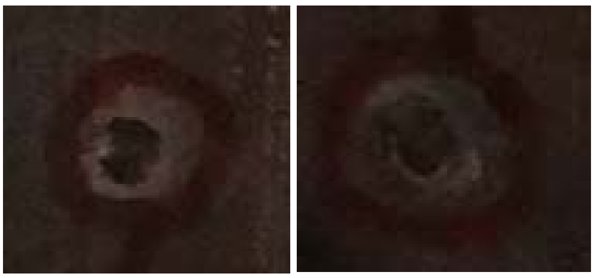


Figure 7: Drilled Hole with Evacuated Material by Type-I Drill Bit

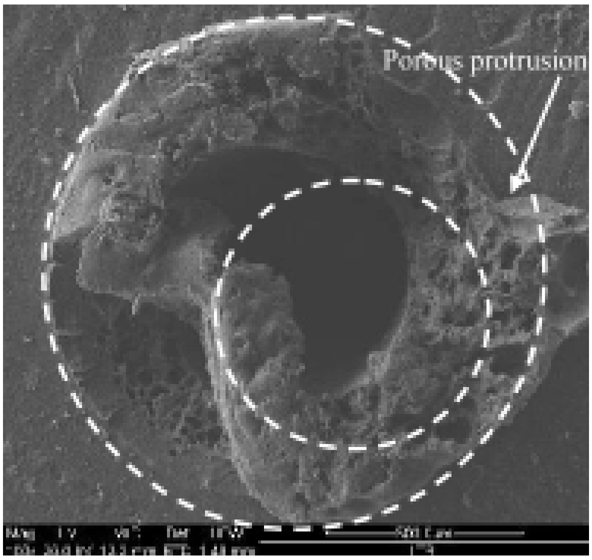
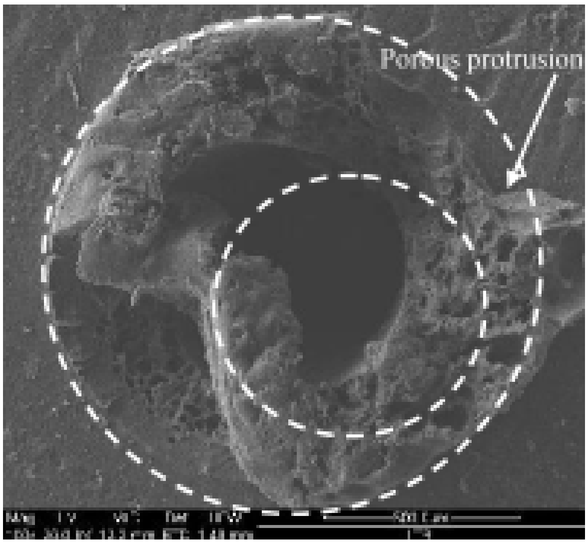


Table 2: EDS Analysis of Porous Material

Element	Weight %	Atomic %
C	59.51 (63.74*)	66.57 (70.27*)
O	39.51 (35.57*)	33.18 (29.44*)
Cr	0.58	0.15
Fe	0.40	0.10
Totals	**100.00**	

Note: * Before microwave drilling.

Figure 7: Drilled Hole with Evacuated Material by Type-I Drill Bit



A typical drilled hole with Type-II drill bit is shown in Figure 8. The results appears similar to that of Type-I. The drilled hole diameter so obtained was about 1.9 mm and a depth of 5 mm. The hole diameter however, was about 35.71% more than the copper drill bit diameter.

Figure 8: Drilled Hole with Ejected Material by Type-II Drill Bit

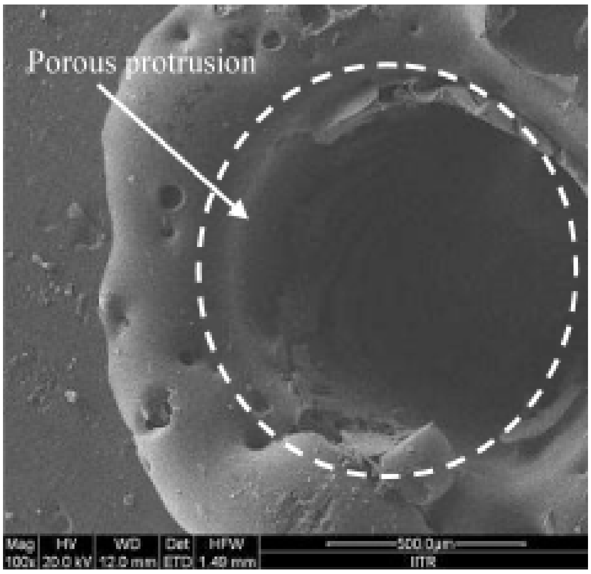


Figure 9: Perspex and Tool Burning by Type-I Drill Bit

This shows that the steel drill bit contribute more towards drilling oversized hole as compared to copper drill bit. The depth of hole drilled with steel bit was limited and most of the time, caused burning of the specimen, if over exposed, as shown in Figure 9. The steel bit form porous material after burnout but able to drill the 11 mm work material depth completely. The tool burnout problem was least with copper drill bit.

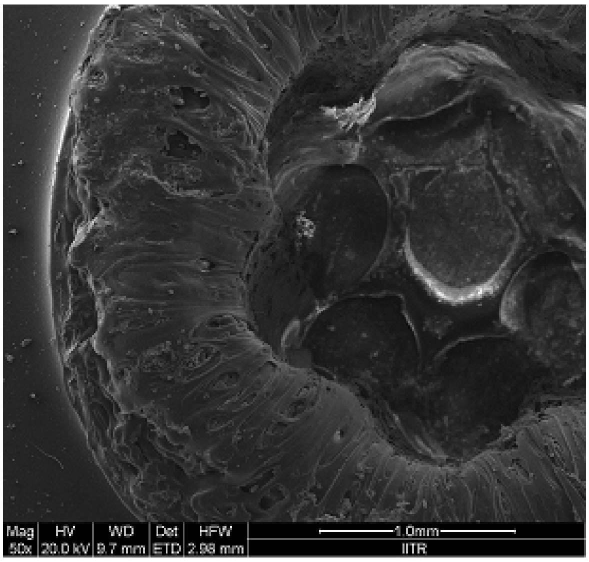
Type-III grooved drill bit (steel) showed poor hole formation with maximum burnout at various spots around the bit. The depth of penetration of the drill bit was also the minimum of all the types of drill bit. Likewise Type-IV fluxed drill bit showed no effect of flux on the

Figure 10: Hole Drilled by Long Tapered Drill Bit

quality of hole and yielded similar hole as observed for Type-I drill bit. Type-V drill bit hole quality was better among all the drill bits which is shown in Figure 10. The holes lack in depth of penetration and was limited to 4 mm depth. The small tapered drill bit Type-Vb showed better hole depth than that of Type-Va drill bit.

Litz wire drilled hole is shown in Figure 11, with impression of all seven strands of copper. The hole drilled are not perfectly circular due to the shape of the drill bit. The material around the drilled hole was less porous as compared to material obtained with other drill bit. The depth of penetration obtained was 3 mm in perspex work material. The blind hole shown in Figure 11 also showed some traces of copper. The presence of metallic material shows wear of drill bit in microwave drilling. Wear of copper drill bit, for all the experiments, was less than that of steel drill bit.

Figure 11: Hole Drilled by Litz Wire Drill Bit



It has been found that the variation in length of the drill bit is not as important, as the depth of penetration in the experimentation was very small. The variation in length helps in adding weight to drill bit during experimentation. It is clear from the comparison that the Type-III grooved drill bit is the most suitable tool in the customized microwave drilling setup, however the experimental results showed frequent burning and over sizing of the hole with poor depth of penetration. Type-VI Litz wire drill bit is next suitable for drilling hole, but fails to generate completely circular hole. Flux coated Type-IV drill bit made of mild steel forms oversized hole with redundant effect of flux in drilling. Thinner drill bit Type-I, Type-II, Type-Va and Type-Vb gives better hole formation. These drill bits require higher self weight for better hole quality and depth of penetration. Drill holders used for Type-I and Type-II drill bits provide necessary self weight, whereas Type Va and Vb doest not require any separate holders. A summary of these observations are presented in Table 3.

Table 3: Drilling Observations with Various Drill Bit

Tool Type	Oversize (%)	Hole Depth (mm)	Perspex Burn Out	Tool Wear (g)
I	90.4	3	yes	0.191
II	35.71	5	less	0.025
III	96.54	2	more	0.102
IV	88.36	3	yes	0.123
Va	30.81	3	less	0.012
Vb	32.47	4	less	0.010
VI	38.63	3	yes	0.041

The steel drill bit in the experimental setup causes various defects such as erratic burning of tool and perspex, ledge formation and uneven hole formation. The quality of hole formed by copper drill bit were marginally better than holes formed by steel drill bit in terms of size and depth of hole. The tapered drill bit with minimum taper angle yielded the smoothest and clear hole during experimentation.

CONCLUSION

Various drill bits were tested for their feasibility to drill hole with microwave energy. It was observed that for almost all drill bit the time for drilling hole was in few seconds. The copper drill bit was identified to be more effective for microwave drilling on microwave transparent material. Proper shape, size and weight of copper tool have more influence on drilling hole in perspex work material. Further, copper experience less tool wear and exhibits better hole drilling capability over steel drill bits. The cross section of the drill bit has to be minimum but stable in order to withstand the self weight and heating due to microwave energy.

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