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IMPACT OF AVERAGE GRAIN SIZE & CONCENTRATION OF POWDER IN PMEDM ON SURFACE ROUGHNESS OF INCONEL-718

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Keywords:

Surface roughness;
Si powder;
Average grain size;
Powder concentration;
Inconel-718.

Abstract

The addition of powder in the dielectric modifies some process variables and creates the conditions for obtaining high surface quality. Powder Mixed Electrical Discharge Machining (PMEDM) is relatively a new development in the direction of enhancement of process capabilities of EDM and considerably improves the surface integrity by reducing the formation of white crystals and scratches, heat affected zone, craters, hollow cavities and micro-cracks on EDMed surface. However, Low Surface Finish is main problem which are being faced in EDM of Inconel-718, one of the most useful Super alloy. There is needed to look at various possibilities for improving SF of Inconel-718. One way is to use some powders in dielectric fluid of EDM. A few investigations on PMEDM of Inconel-718 indicate that pure Silicon (Si) powder mixed with dielectric gave encourage results. The present work is also in the same direction and detailed experimental study has been conducted. The average grain sizes i.e. 15µm, 25µm and 40µm of Si powder particles and their concentration are taken as input parameters. Final surface roughness, surface profiles and SEM photographs have been obtained at various combinations of the input parameters. On an average, 40% improvement in SF has been observed, when Inconel-718 was machined by PMEDM instead of EDM. Comparison of SEM photographs reveals noticeable decrease in surface cracks when Inconel-718 was machined with PMEDM.

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1. Introduction

Electrical discharge machining (EDM) is a technological process with a large industrial implementation. Its use is particularly intense when very complex shapes on hard materials with a high geometrical and dimensional accuracy are required. However, the technological capability of the process has limited its application when the specification of the part surface quality imposes polished and mirror-like characteristics. The addition of powder particles in suspension in the dielectric modifies some process variables and creates the conditions to achieve a high surface quality in large areas [10]. A silicon powder was used and the improvement is assessed through quality surface indicators and process time measurements,

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over a set of different processing areas. The positive influence of Si powder in the reduction of the operating time and allowing the generation of mirror like surfaces [1]

PMEDM is one of the non-conventional machining processes applications, particularly for intricate shapes on hard materials with high dimensional accuracy requirements which is otherwise not possible by conventional machining methods. A suitable material in the powder form is mixed into the dielectric fluid of EDM. When a voltage of 80–320V is applied to both the electrodes, an electric field in the range 105–107 V/m is created. The spark gap is filled up with additive particles and the gap distance setup between tool and the work-piece increased from 25–50 to 50–150µm. The addition of powder leads to an increase in gap size that subsequently resulted in a reduction in electrical discharge power density and in gas explosive pressure for a single power pulse [2, 8].

Electrical discharge machining (EDM) is most important advantage is that its effectiveness is regardless of the mechanical properties of the machined materials. Hence, titanium, which is a difficult-to-machine material, can be machined effectively by EDM. However, EDMd surfaces have defects of micro cracks and pores formed by the strong temperature gradient during machining. These defects result not only in poor surface precision, but also in a shortened service life of machinery parts. Therefore, a work piece must be coated with a hard material in a post machining process after EDM to improve its poor surface properties. Such subsequent treatment yields surfaces that can be used in industrial applications, but greatly increases fabricating time and cost. Thus, researchers are very interested in developing surface modification technology that can be easily operated and low cost to improve the mechanical properties of machined surfaces [3].

Green manufacturing technology has recently become very important to all manufacturing industries. Pure water and the SiC powder produce a good post-process treatment without any environmental pollution. SiC powder was added to pure water as a working fluid to verify the micro-slit EDM process performance. The addition of SiC powder would increase working fluid electrical conductivity, enlarge the electrode and workpiece gap, and also extrude debris easily, therefore increasing the material removal rate [9-10]. Furthermore, the use of SiC powder helped bridge the electrode and workpiece gap and disperse discharge energy, thus creating two discrete discharging pulses from a single discharging period that could effectively disperse discharging energy into several increments [4]. The discharging results could then generate a minor crater and debris since minor debris would ease gap exhaust and accelerate material removal rate. The minor crater could simultaneously refine the surface roughness.

The addition of both SiC and aluminum powder to the kerosene permit an extension of the gap between the electrode and the workpiece. The extended gap increases the debris removal rate and the material removal depth. Furthermore, a bridging effect is created by the added powder drifting within the kerosene and, in doing so, facilitates the dispersion of the discharge into several increments. Thus, several discharging trajectories are formed within a single input impulse and several discharging spots are created within a discharging impulse also. The effects due to the discrete discharging pulses are elucidated, these effects being the minimizing of the machined debris, which is easily removed, and the increasing of the material removal depth and surface roughness. However, the addition of the powder to the kerosene disturbs the adherence of carbon nuclides attached to the surface of the electrodes [5].

2. Experimental procedure

The electric discharge machine, model Sparkonix SEM model SN25 (die-sinking type) with servo-head was used to conduct the experiments. Commercial grade EDM oil (kerosene) was used as dielectric fluid. An external dielectric circulation loop has been built for the purpose of using powder added dielectrics. In order to prevent powder particles accumulation on horizontal plane surfaces, the dielectric tank has been designed conical as shown in figure 1. The flushing pipes have been designed to get the dielectric directly from the conical tank. This design leads to reproducible and constant powder concentration in the dielectric fluid [6]. The conical dielectric tank has been designed and ensures the uniform or constant powder concentration of the powder particles in the dielectric fluid was ensured. There is no any accumulation of the powder particles on horizontal plane surfaces (i.e. bottom of dielectric tank). Flow rate of Powder mixed dielectric fluid and flushing system has been properly maintained.

The Ni-based super-alloys (Inconel-718), tungsten carbide and kerosene oil has been used as work material, electrode material and dielectric fluid respectively in PMEDM. Only two input parameters (powder grain size and concentration of powder) have been varied and rest of all the parameters (like peak current, pulse on time, off time, duty cycle etc) kept constant. A commercial available silicon powder with three different particle grain sizes has been chosen for experimentation. The average grain sizes like 15µm, 25µm and 40µm has been taken. SEM analysis has been used to show the morphology of machined surfaces at different grain sizes of powder and concentration. Optical profile-meter (OPM) examined machined surfaces, which gave the value of Ra (surface roughness) at various levels of tests.

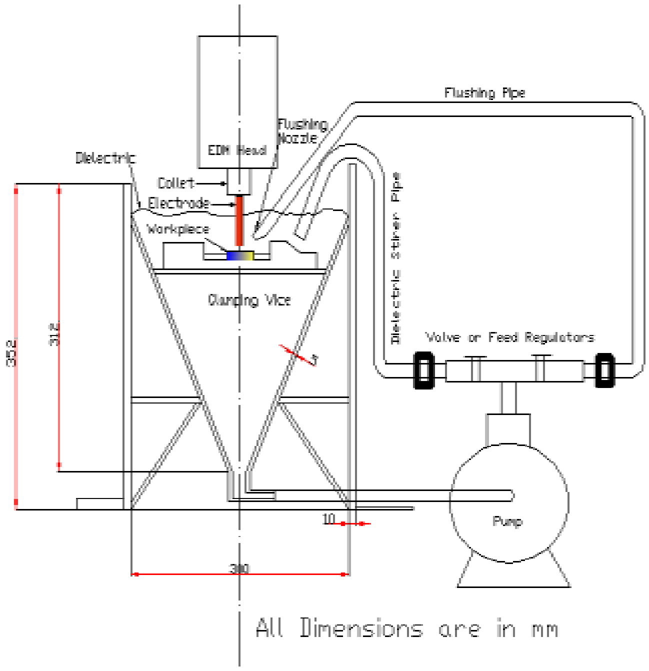


Figure 1. *The Experimental set-up and powder mixed attachement [6].*

3. Results & Discussion

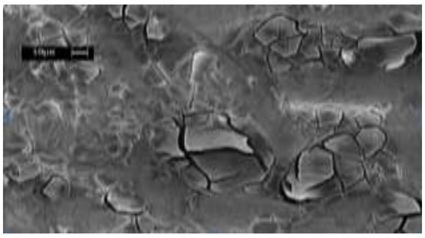
From the results obtained by experimentation, the attempt has been made to study the impact of silicon powder concentration and average grain size over surface characteristics like surface roughness, formation of pits, variation of deeper and wider cracks or craters, scratches discuss in the following three cases for three different grain sizes in detail:

Case I: Silicon Powder Average Grain size of 15 µm

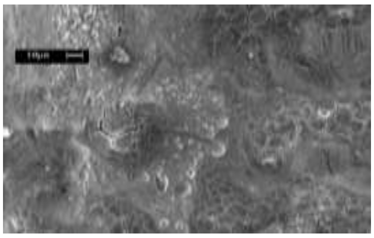
As previous research work reveals that the locally concentrated spark energy causes irregularity of machined surface cracks, local fracture & breakage of work piece. In this process, the work piece to be machined under experiment set up is placed without concentration i.e. C=0 of silicon powder. The surface textures obtained at different concentration of powder with a peak current of 3A revealed by SEM (Scanning Electron Microscopy) is shown in Figure 2. The SEM photographs as shown in Figure 2 (a) reveals that at some area of scanned surface of work piece, the surface roughness is more and the percentage of the surface cracks is about more than 70% along with a few percentage of shallow cracks. Further, by the use of Si powder particles, there was an evident decrease of deep cracks & fractures on the machined surface of the work piece. From SEM images shown from Figure 2 (b)-(g) and surface roughness data as depicted in Table 1 obtained from optical profilometer, it shows that the surface becomes more fine and smooth at the powder concentration of 10gm/ltr and reduced to 2.43 µm as shown in Figure 2 (f). However, when the silicon powder concentration is kept equal or more than that of 12gm/ltr, the surface roughness, deep cracks and scratches rises due arcing in a large amount again along with the increase in width of the two consecutive cracks, as shown in Figure 2 (g).

Table 1: Concentration 'C' and Surface Roughness data for Grain size of 15µm

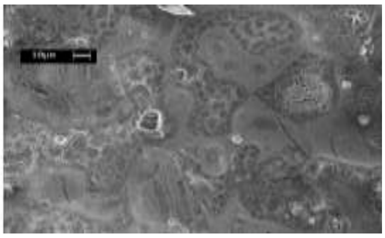
S.No	Concentration 'C' (gm/ltr)	Surface Roughness 'R_a'(µm)
1	0	5.91
2	2	4.14
3	4	3.69
4	6	3.37
5	8	2.83
6	10	2.43
7	12	2.81



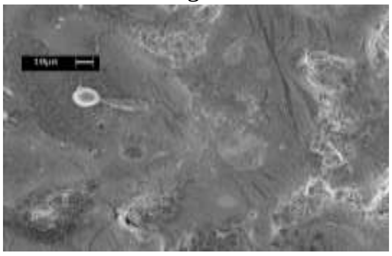
(a) Without powder concentration, C=0gm/ltr



(b) With powder concentration, C=2gm/ltr

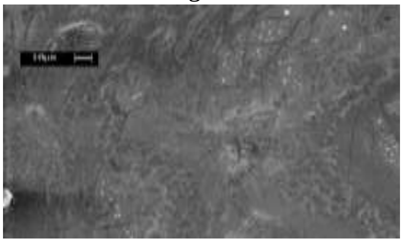


(c) With powder concentration, C=4gm/lt

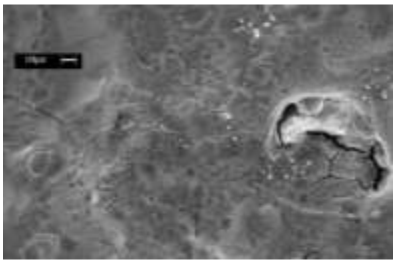


(d) With powder concentration, C=6gm/ltr

(e) With powder concentration, C=8gm/ltr



(f) With powder concentration, C=10gm/ltr

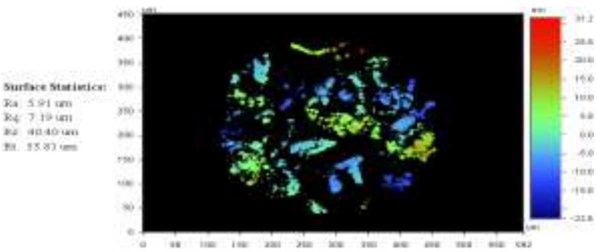


(g) With powder concentration, C=12gm/ltr

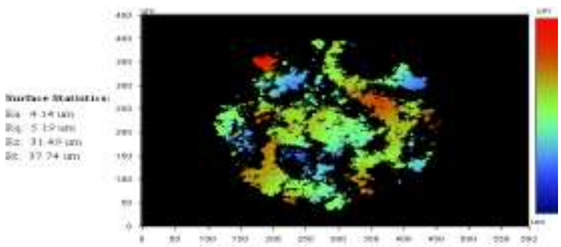
Figure 2. *SEM Photographs of PMEDMed Workpieces at various Concentrations for average Grain Size of Silicon Powder particles of 15µm.*

Also, it shows that at high value of powder concentration at or more than 12gm/ltr, deeper craters are formed, which are shown by the dark grey color on the SEM photographs. Few white crystals are also observed, which may be formed due to the deposition of debris and powder particles during machining process.

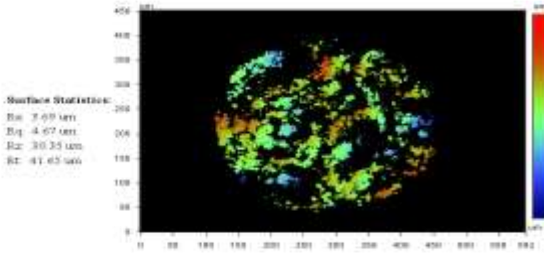
So, from above discussion and experimental results, it is possible to conclude that the presence of silicon powder, with appropriate concentration, not only reduces the crater diameter but also significantly reduces the crater depth and the melted material overflow. Further, the Optical Profilometer Images of average silicon-powder grain size of 15µm as shown in Figure 3 (a)-(f) with different powder concentration presents the surface characteristics of the work piece (Inconel- 718) which is measured by the color presentation of deeper craters (represented by blue color), crests (represented by red color) and the smoother surface ((represented by green color). With zero powder concentration, Image shown in Figure 3 (a) reveals that the percentage of blue color is more than that of the percentage of green color, which means the percentage of the deep and wider surface cracks along with a few percentages of shallow cracks is large in this case and increase Surface Roughness to 5.91µm. The Figure 3 (e) shows the maximum percentage of green color i.e. maximum surface smoothness and decreases the Surface Roughness to 2.43µm at powder concentration of 10g/litre. On further increment in the concentration of silicon powder particles (>10gm/ltr) increases the surface roughness again as shown in Figure 3 (f) and as discussed previously.



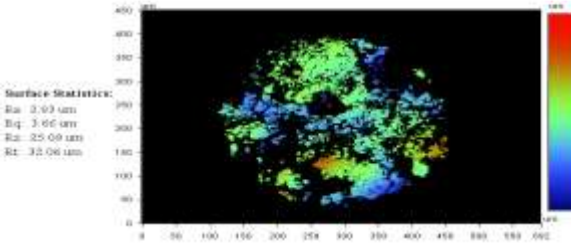
(a) Without powder concentration, C=0 gm/ltr



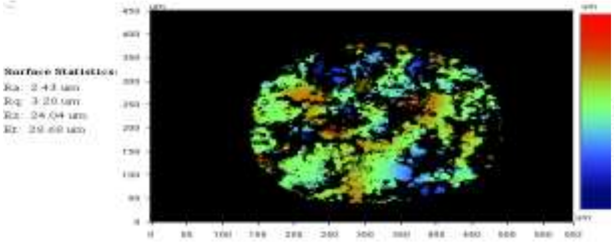
(b) With powder concentration, C=2 gm/ltr



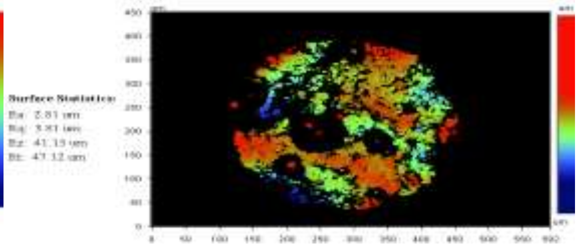
(c) With powder concentration, C=4 gm/ltr



(d) With powder concentration, C=8 gm/ltr



(e) With powder concentration, C=10 gm/ltr

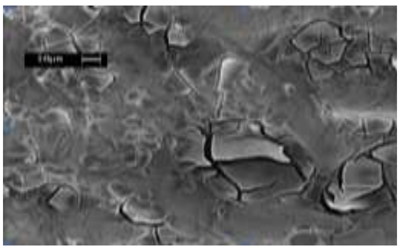


(f) With powder concentration, C=12 gm/ltr

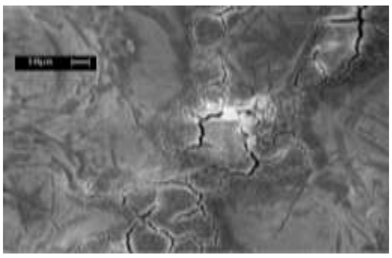
Figure 3. *Optical Profilometer Images for Average Grain size of 15µm for PMEDMed Workpieces at various concentrations*.

Case II: Silicon Powder Average Grain size of 25 µm

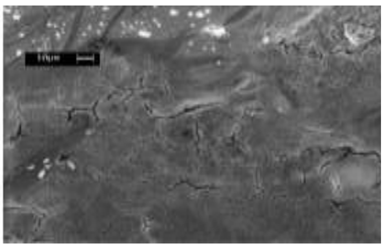
As discussed in previous case, the work piece to be machined under experiment set up with concentration i.e. C=0 of silicon powder, the value of surface roughness, R_a = 5.91 is calculated and more surface roughness, deeper and wider surface cracks along with a few percentage of shallow cracks are observed as shown in Figure 4(a). Further, by the use of Si powder particles of Grain size 25µm with different powder concentration, no doubt we experience of less deeper cracks & fractures on the machined surface of the work piece but white spots/crystals are also observed which may be due to the deposition of debris and powder particles as shown in Figure 4 (b)-(d) but decreases with the increase of powder concentration. Further, it is also observed that the percentage of these white spots are almost negligible at the concentration of 10gm/ltr (Figure 4 (f)) but again rises as further increase the powder concentration equal or more than that of 12gm/ltr as shown in Figure 4 (g). From SEM images shown from Figure 4 (b)-(g) and surface roughness data as depicted in Table 2 obtained from optical profilometer, it shows that the surface becomes finer and smoother at the powder concentration of 10gm/ltr and reduced to 2.34 µm as shown in Figure 4 (f) and provide maximum MRR.



(a) Without powder concentration, C=0 gm/ltr

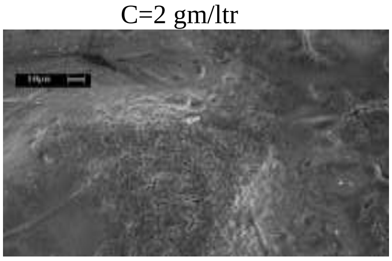


(b) With powder concentration, C=2 gm/ltr

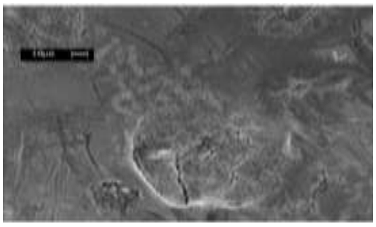


(c) With powder concentration, C=4 gm/ltr

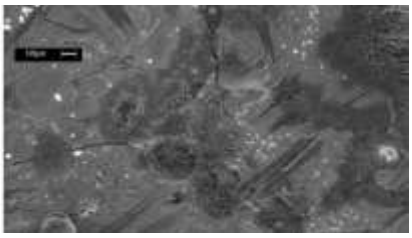
(d) With powder concentration, C=6 gm/ltr



(e) With powder concentration, C=8 gm/ltr



(f) With powder concentration, C=10 gm/ltr



(g) With powder concentration, C=12 gm/ltr

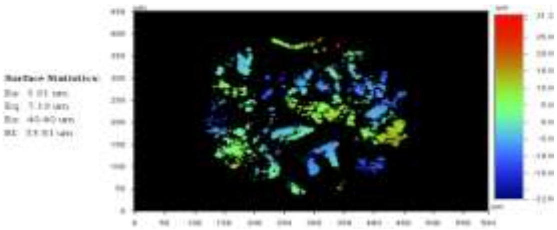
Figure 4. *SEM Photographs of PMEDMed Workpieces at various Concentrations for average Grain Size of Silicon Powder particles of 25μm.*

Also, it shows that at high value of powder concentration at or more than 12gm/ltr, deeper craters are formed, which are shown by the dark grey color on the SEM photographs. Few scratches are also observed, which may be come into picture due to the arcing induced in between the tool used and the work piece at high concentration of powder.

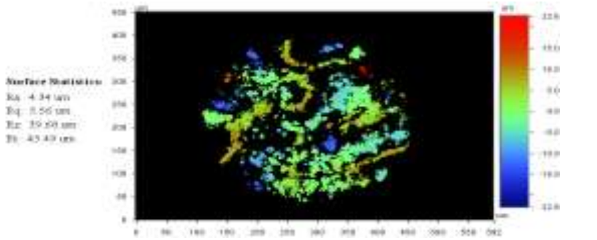
Table 2: Concentration 'C' and Surface Roughness data for Grain size of 25μm

S.No	Concentration 'C' (gm/ltr)	Surface Roughness 'R_a' (μm)
1	0	5.91
2	2	4.34
3	4	3.69
4	6	3.59
5	8	2.96
6	10	2.47
7	12	3.71

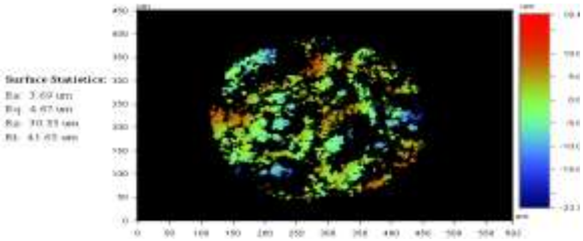
So, from above discussion and experimental results, it is possible to conclude that the presence of silicon powder, with appropriate concentration, not only reduces the crater diameter and depth but also significantly reduces the percentage of white crystals and scraches.



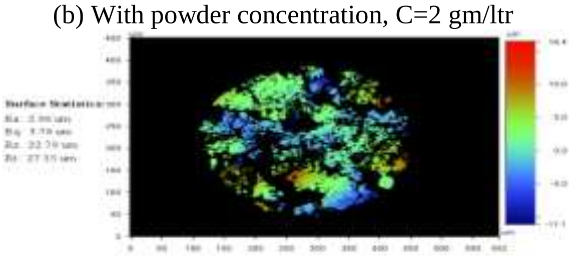
(a) Without powder concentration, C=0 gm/ltr



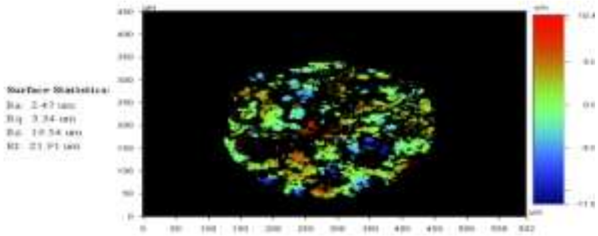
(b) With powder concentration, C=2 gm/ltr



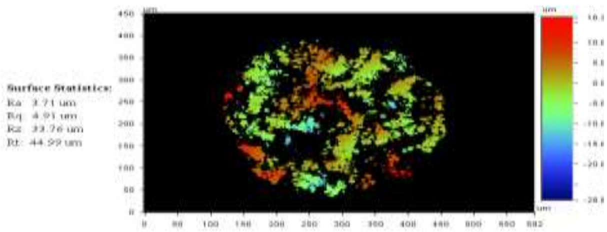
(c) With powder concentration, C=4 gm/ltr



(d) With powder concentration, C=8 gm/ltr



(e) With powder concentration, C=10 gm/ltr



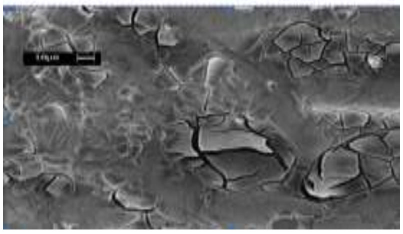
(f) With powder concentration, C=12 gm/ltr

Figure 5. *Optical Profilometer Images for Average Grain size of 25μm for PMEDMed Workpieces at various concentrations.*

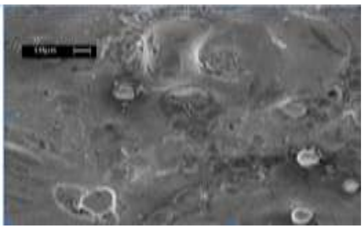
Further, we describe the variation of surface roughness with respect to the silicon powder concentration at different grain sizes with the help of the Optical Profilometer Images as shown in Figure 5 (a)-(f)
With zero powder concentration, Image shown in Figure 5 (a) reveals that the percentage of blue color is more than that of the percentage of green color, which means the percentage of the deep and wider surface cracks along with a few percentages of shallow cracks is large in this case and increase Surface Roughness to 5.91µm. The Figure 5 (e) shows the maximum percentage of green color i.e. maximum surface smoothness and decreases the Surface Roughness to 2.43µm at powder concentration of 10gm/ltr. On further increment in the concentration of silicon powder particles (> 10gm/ltr) increases the surface roughness again as shown in Figure 5 (f) and as discussed previously.

CASE III: Silicon Powder Average Grain size of 40 µm

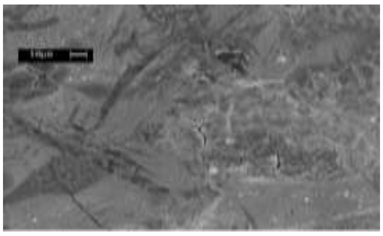
The Figure 6 (a) represents the surface roughness, deeper and wider surface cracks along with a few percentage of shallow cracks with concentration i.e. C=0 of silicon powder and calculates the value of surface roughness as, $R_a = 5.91$.



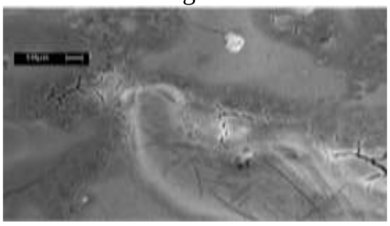
(a) Without powder concentration, C=0 gm/ltr



(b) With powder concentration, C=2 gm/ltr

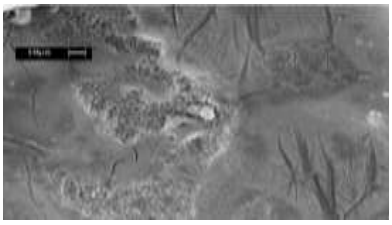


(c) With powder concentration, C=4 gm/ltr

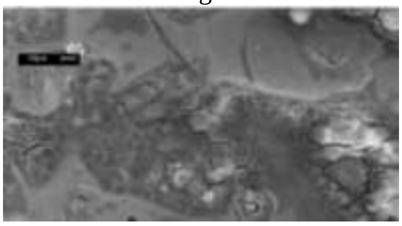


(d) With powder concentration, C=6 gm/ltr

(e) With powder concentration, C=8 gm/ltr



(f) With powder concentration, C=10 gm/ltr



(g) With powder concentration, C=12 gm/ltr

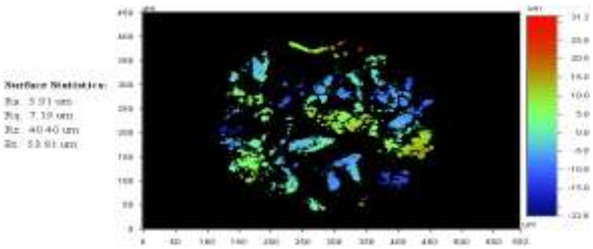
Figure 6 *SEM Photographs of PMEDMed Workpiece at various Concentrations for average Grain Size of Silicon Powder particles of 40µm*.

In Figure 6, we observed Light Grey Zone (LGZ), White Reflection Zone (WRZ) and under the beneath of LGZ zone, another Dark Grey Zone (DGZ) is observed. The white zone may be due to the re-solidification of molten metal along with powder particle during machining process and reduces as the concentration of silicon powder increases up to 8g/litre as shown in Figure 6 (a)-(f) and again increases on increasing the concentration of silicon powder further. The presence of white crystals is more at powder concentration of 8 gm/ltr in this case as compare to the two previous discussed cases because of the increases of grain size, which reveals that not only the silicon powder concentration but also the grain size effect the surface roughness of the work piece material. The LGZ zone reflects the smoothness of surface and percentage of this zone increases as we increase the powder concentration and reduces as we increase the grain size. While DGZ zone is the pictorial presentation of surface roughness, which increases as grain size increases and decreases as powder concentration increases but to an optimum value only. Further, by the use of conductive powder particles of Grain size 40µm with different powder concentration, no doubt we experience of less deeper cracks & fractures on the machined surface of the work piece as shown in Figure 6 (b)-(d) but decreases with the increase of powder concentration. Further, it is also observed that the percentage of these white spots are almost negligible at the concentration of 8gm/ltr (Figure 6 (e)) but again rises as we further increase the powder concentration equal or more than that of 10g/litre as shown in Figure 6 (f). From SEM images shown from Figure 6 (b)-(g) and surface roughness data as depicted in Table 3 obtained from optical profilometer, it shows that the surface becomes finer and smoother at the powder concentration of 8gm/ltr and reduced to 3.07 µm as shown in Figure 6 (e). Also, it shows that at high value of powder concentration at or more than 8gm/ltr, deeper craters are formed, which are shown by the dark grey color on the SEM photographs. Few scratches are also observed, which may be come into picture due to the arcing induced in between the tool used and the work piece at high concentration of powder. So, from above discussion and experimental results, it is possible to conclude that the presence of silicon powder, with appropriate concentration, not only reduces the crater diameter and depth but also significantly reduces the percentage of white crystals and scratches.

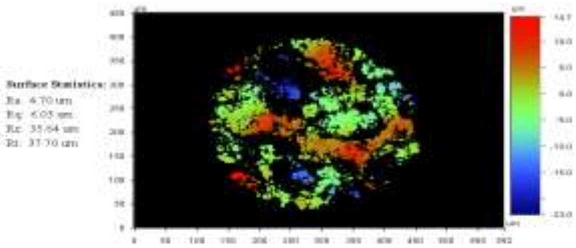
Table 3: Concentration ‘C’ and Surface Roughness data for Grain size of 40µm

S.No	**Concentration ‘C’ (gm/ltr)**	**Surface Roughness ‘R_a’(µm)**
1	**0**	**5.91**
2	**2**	**4.70**
3	**4**	**4.17**
4	**6**	**3.93**
5	**8**	**3.07**
6	**10**	**3.45**
7	**12**	**4.17**

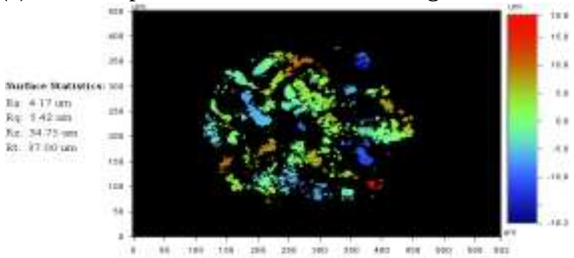
Further, we describe the variation of surface roughness with respect to the silicon powder concentration at different grain sizes with the help of the Optical Profilometer Images as shown in Figure 7 (a)-(f). With zero powder concentration, Image shown in Figure 7 (a) reveals that the value of Surface Roughness obtained is 5.91µm as discussed previously.



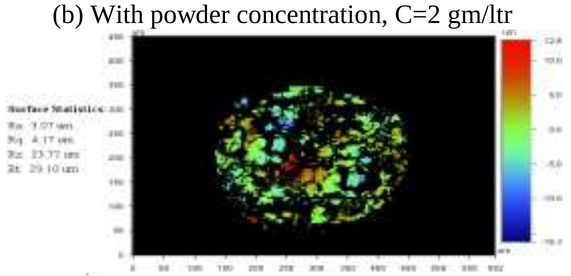
(a) Without powder concentration, C=0 gm/ltr



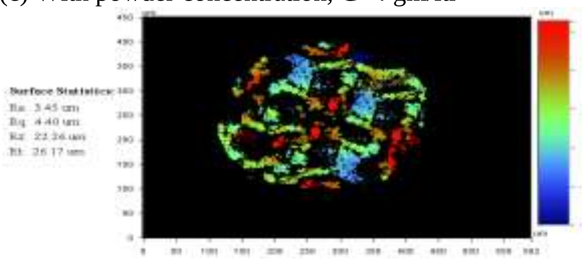
(b) With powder concentration, C=2 gm/ltr



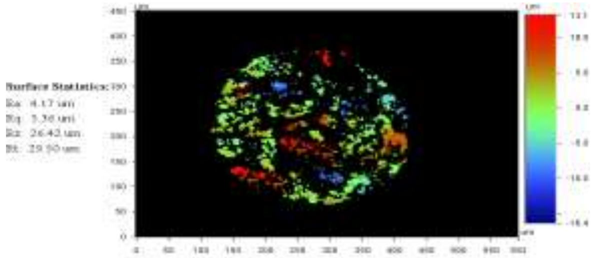
(c) With powder concentration, C=4 gm/ltr



(d) With powder concentration, C=8 gm/ltr



(e) With powder concentration, C=10 gm/ltr



(f) With powder concentration, C=12 gm/ltr

Figure 7. *Optical Profilometer Images for Average Grain size of 40µm for PMEDMed Workpieces at various concentrations.*

The Figure 7 (d) shows the maximum percentage of green color i.e. maximum surface smoothness and decreases the Surface Roughness to 3.07µm at powder concentration of 8g/ltr. On further increment in the concentration of silicon powder particles (> 8g/ltr) increases the surface roughness again as shown in Figure 7 (f) and as discussed Case I and II.

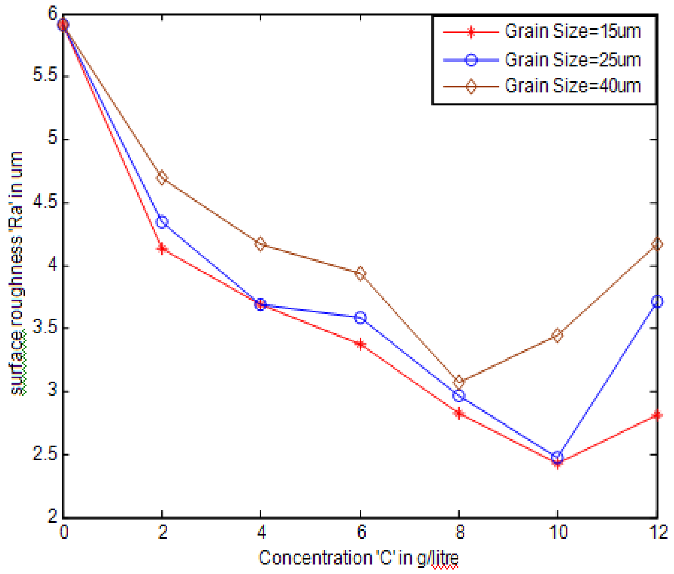


Figure 8. *Surface Roughness 'R_a' versus concentration 'C' at different Grain sizes*

The graphical presentation in figure 8-9 reveals that with grain size of 15 µm, the surface finish is more and also obtained the maximum value at powder concentration of 10g/ltr in both the cases of Grain size of 15 µm and 25 µm but obtained the maximum value at 8g/ltr with 40 µm. A larger diameter of the powder particles increases the gap and increases the surface roughness (R_a). So, we conclude that the best results are obtained for powder particles with diameter of 15 µm as shown in Figure 9 and Table 4.

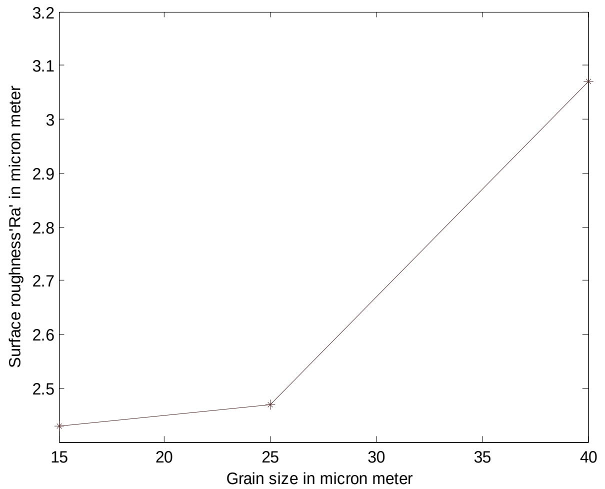


Figure 9. *Surface Roughness versus different Grain sizes of powder with current 3A; Pulse ON Time 6µs; Pulse OFF Time 5µs*

Table 4: Average Grain size versus Surface Roughness

S.No	Grain size (µm)	Surface Roughness 'R_a' (µm)
1	15	2.43
2	25	2.47
3	40	3.07

4. Conclusion

In this experimental work, a silicon powder-mixed electro discharge machining method is used to produce holes of 2mm diameter in a work piece of Inconel-718 and the impact of Silicon Powder Concentration and Average Grain Size over Surface Roughness is analyzed. Within the range of selected parameters, following conclusions are drawn from this work:

I. On an average, 40% improvement in SF has been observed, when Inconel-718 was machined by PMEDM (with suitable addition of pure Si Powder) instead of EDM.

II. Comparison of SEM photographs reveals noticeable decrease in surface cracks when Inconel-718 was machined with PMEDM as compare to EDM. It is concluded that the surface becomes finer and smoother at the powder concentration of 10gm/ltr and reduced to 2.43µm for 15µm grain size.

III. Surface profile of EDMed and PMEDMed workpieces revealed clear improvement of surface condition as regards to uniformity of grain structure. Uniform cratering has been observed in case of profiles generated from PMEDMed workpieces.

IV. Surface roughness (R_a) increases on increasing the Grain size of powder particles.

V. The best values of concentration and out of chosen grain sizes of silicon powder for Inconel-718 is 10gm/ltr and 15µm respectively.

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