Development
Of
Diamond Cutting Tool (DCT)

Research work carried out by,
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1. Preamble

The aim of the undertaking study was to evaluate the performance of electrolytic iron powder esp. thermally reduced (TR grade) for manufacturing Diamond Cutting Tools (DCT) that are widely used for marble/stone cutting application in northern region of India. The present survey carried out by the research team in Udaipur and Jaipur revealed that diamond cutting tool industries are involved in manufacturing DCTs based on inconsistent approaches. The basic concept of making diamond cutting tools varies from industry to industry without / limited scientific back up. Traditionally imported carbonyl iron powder occupies about 50 % in the overall composition of the DCT. Through this work, a rigorous attempt is made to replace carbonyl iron powder by TR grade electrolytic iron powder produced by IMP. Another attempt in the proposed work was to investigate the stability of DCTs at various levels of loads and sliding speeds employed and its service conditions were simulated in laboratory wear test machine. This has led to the wear design map.

2. Materials used for manufacturing DCTs

The materials selected in the manufacturing DCTs are listed in the Table-1. In the work, all possible combinations employed by the diamond cutting industries for manufacturing DCTs are attempted and their properties are evaluated.

Table 1: Properties of the powders used for manufacturing of diamond cutting tools

Sr. No.	Powder	Particle size (micron)	ASTM Particle Size (mesh)	Apparent density (g/cc)	Make
1	Electrolytic iron (TR Grade)	2.4	* 2400	1.61	Industrial Metal powder Pune
2	Carbonyl iron	2.58	* 2400	3.15	Imported
3	Electrolytic Copper	4.5	* 2400	1.20	Local
4	Cobalt	1.45	* 4800	1.40	Umicore
5	Nickel	105	140	4.10	Imported
6	FTC	37 - 44	-325 + 400	6.07	Electronica
7	Aluminum	91	140	1.18	Komal Atomizer
8	Magnesium	52	270	0.64	Local
9	Tin	44	325	4.05	Vivek agencies
10	Synthetic diamonds	250/300	50/60	3.52	Imported

N.B. * is the equivalent mesh size.

3. Flow chart for the of DCT manufacturing process

The process followed for the fabrication of DCT is shown in the form of flow chart as shown in Fig.1 and various compositions of DCTs are attempted as given in Table-2. The hot-pressed sintering cycle followed is shown in Fig.2. The DCTs fabricated by following hot-press sintering process is depicted by Fig.3.

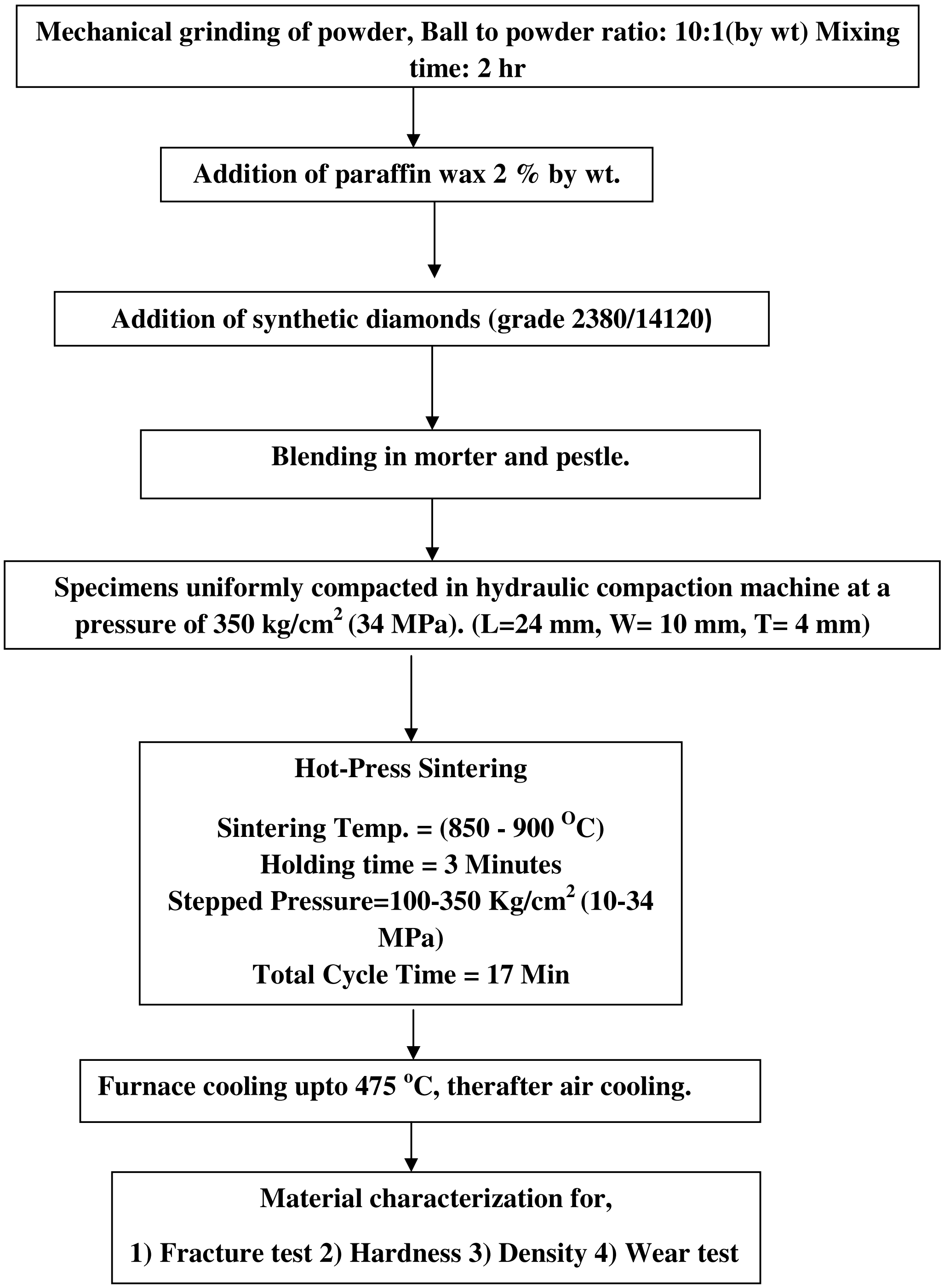


Fig.1: Flow chart for manufacturing DCTs using hot-pressed sintering furnace

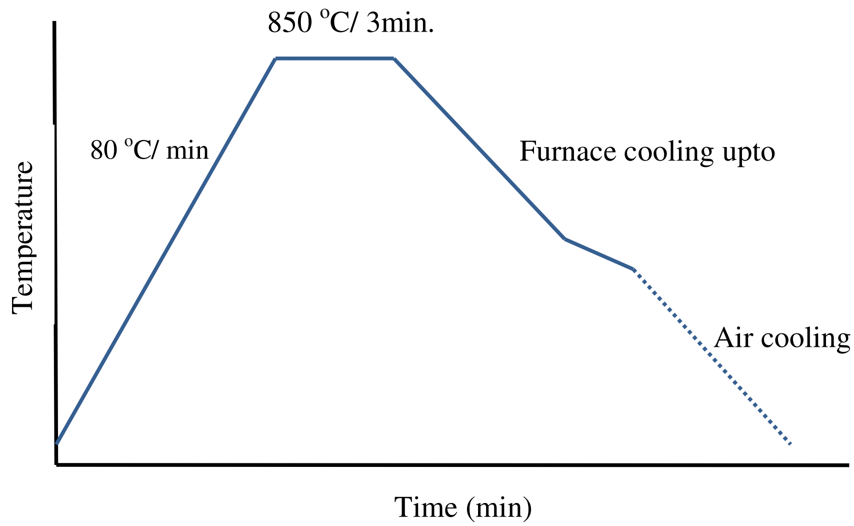


Fig.2: Hot-press sintering cycle followed for fabrication of DCT

Fig.3: Hot pressed diamond cutting tools made by application of electrolytic iron powder

Table 2: Composition of various mixes tried for the fabrication of diamond cutting tools

Composition No.	C1 & C3	C2 & C4	C5	C6	C7	C8	C9	C10
Sample coding	Base + Ni	Base + Ni +D	Base + Ni+ Sn + D	Base + Ni+ Sn Al,Mg Not Added	Base + Ni+ Sn + D Al,Mg Not Added	Ni free Base	Ni free Base + Sn	Ni free Base +D
% by wt.	Fe : 47.5	Fe : 44.62	Fe : 42.62	Fe : 52,50	Fe : 49.62	Fe : 49.48	Fe : 47.48	Fe : 46.6
	Cu: 13.5	Cu: 13.5	Cu: 13.5	Cu: 13.5	Cu: 13.5	Cu: 13.5	Cu: 13.5	Cu: 13.5
	Co: 20	Co: 20	Co: 20	Co: 20	Co: 20	Co: 20	Co: 20	Co: 20
	FTC : 10	FTC : 10	FTC : 10	FTC : 10	FTC : 10	FTC : 10	FTC : 10	FTC : 10
	Ni : 2	Ni : 2	Ni : 2	Ni : 2	Ni : 2	Ni : 0	Ni : 0	Ni : 0
	Al : 6	Al : 6	Al : 6	Al : 0	Al : 0	Al : 6	Al : 6	Al : 6
	Mg : 1	Mg : 1	Mg : 1	Mg : 0	Mg : 0	Mg : 1	Mg : 1	Mg : 1
	Diamonds: 0	Diamonds: 2.88	Diamonds: 2.88	Diamonds: 0	Diamonds: 2.88	Diamonds : 0	Diamonds: 0	Diamonds: 2.88
	Sn : 0	Sn : 0	Sn : 2	Sn : 2	Sn : 2	Sn : 0	Sn : 2	Sn : 0

N.B: D = Diamond reinforced; Ni = Nickel 2%; Sn = Tin 2%; Base = Without diamond; Ni-free: Nickel not added; FTC=Fused tungsten carbide

3. Results and Discussion

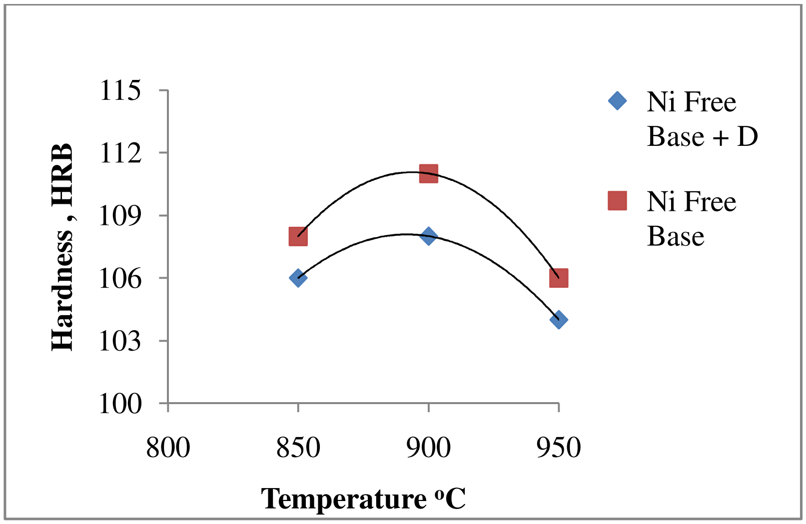
3.1 Effect of sintering temperature on the properties of diamond cutting tools

The tools of composition C8 and C10, as indicated in Table 2, were studied to see the effect of sintering temperature on the properties of DCTs. Table -3 shows overall change in the properties of the DCTs as a function of sintering temperature. The maximum hardness is observed at 900°C as depicted in Fig.4a and sintered density showed increasing trend with increasing temperature (Fig.4b). However, wear rate is almost attain steady state for the sintering temperature in the range of 800-900°C and slight increase trend in wear rate is seen 950°C. Thus improved resistance of DCTs is also corroborated by the retention of sharp cutting edges of diamond particles (Fig.5a, b) till 900°C. But further increase in sintering temperature to 950°C weakens the diamond particles which results in fracturing of diamonds during sliding. It is said that synthetic diamond starts graphitising beyond 900°C.

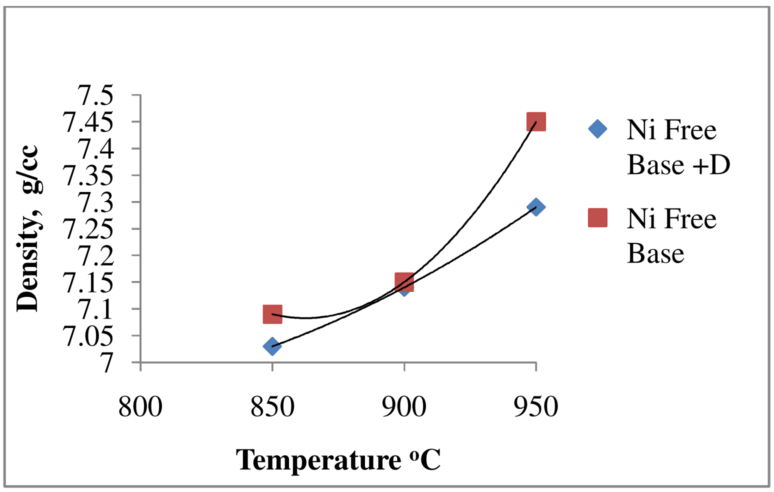
Table 3: Effect of Hot-press sintering temperature on properties of DCTs

	850°C			900°C			950°C		
Sample Coding	Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)	Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)	Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)
*C-8 Ni Free Base	108	7.09	9.67E-04	111	7.15	4.46E-04	106	7.45	12.3E-04
*C-10 Ni Free Base + D	106	7.03	2.02E-04	108	7.14	2.15E-04	104	7.29	3.53E-04

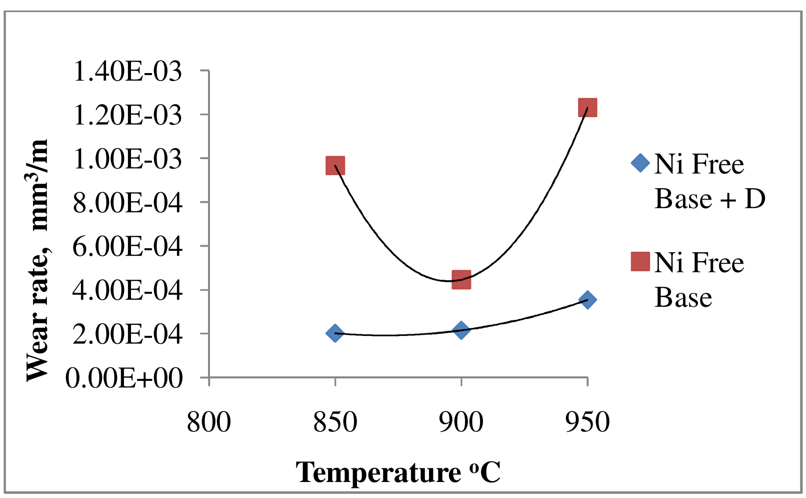
*N.B.*Refer Table 2 for detailed composition of C-8 and C-10. **Parameters for wear test: Load = 2kg, Pressure= 0.4 MPa, Velocity= 2.34 m/s. All hardness and wear rate values were calculated from the average of 6 readings with error of ±3 HRB and ± 15% respectively.*



(a)

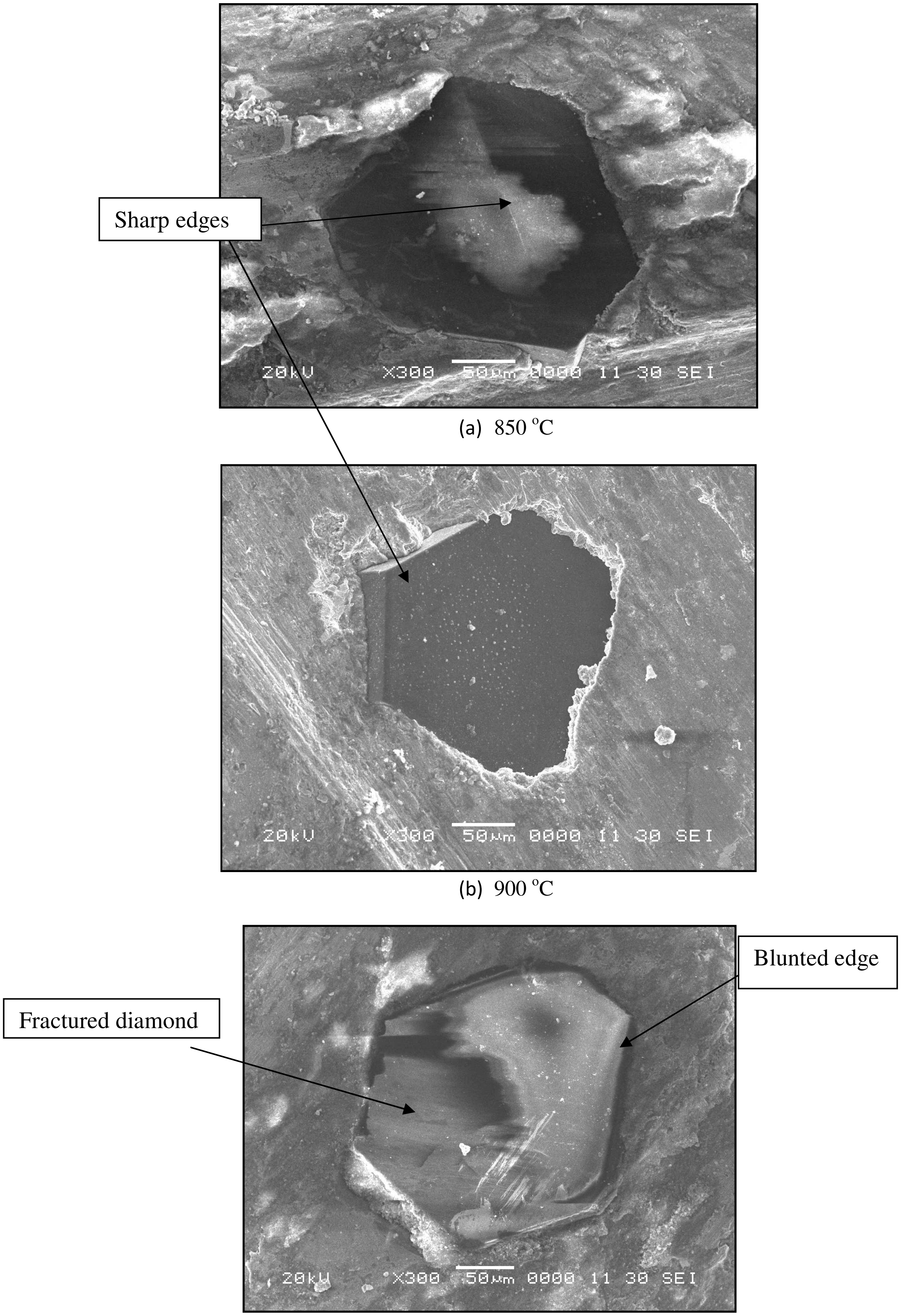


(b)



(c)

Fig.4: (a, b, c): Effect of sintering temperature on the properties of diamond cutting tool (C-8, C10)



(a) 850 °C

(b) 900 °C

(c) 950 °C

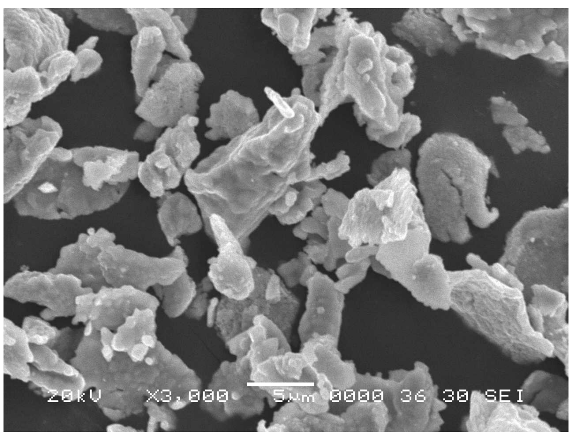
Fig. 5: SEM photograph of diamond cutting tools depicts retention ability of diamonds higher sintering temperatures

3.2 Comparison of hot-pressed sintered Electrolytic iron (E-Fe) and Carbonyl iron (C-Fe) powder compacts

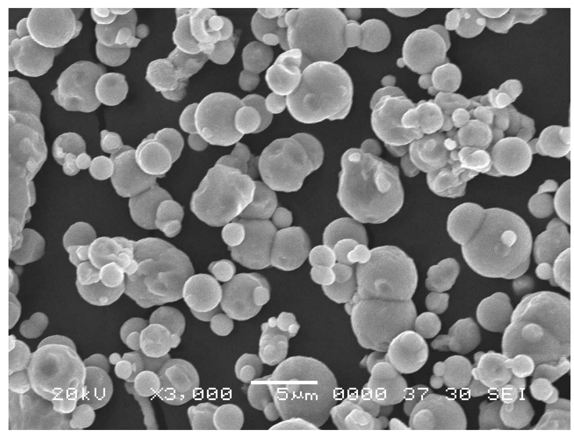
The pure electrolytic and carbonyl iron powders were compacted at 350 kg/cm^2 (34 MPa) and then hot pressed at 850 ^{0}C and hold for 3min at a stepped pressure of 100-350 kg/cm^2 (10 - 34 MPa). The hardness of electrolytic iron powder was much higher than of carbonyl iron powder but density was slightly low. Hence the E-Fe can be used in DCT while the porosity can be filled up by adding suitable alloying elements.

Table 4: Hot-pressed sintered compact properties of iron powders

Parameters	**Electrolytic iron (TR grade)**		**Carbonyl Iron**	
	Without grinding	**With grinding**	**Without grinding**	**With grinding**
Hardness (HRB) (± 3 HRB error)	83	85	64	65
Density (g/cc) (± 0.03 g/cc error)	7.33	7.46	7.53	7.54
% Porosity	6.74	5.08	4.20	4.04



IMP Electrolytic Iron



Carbonyl Iron

Fig 6: SEM morphology of Electrolytic and Carbonyl iron powders (3000X)

3.3 Hot-pressed sintered properties of DCTs made using Electrolytic and Carbonyl iron Powder

Few diamond cutting tools (C1, C2, C3 and C4) were made independently using electrolytic iron powder and carbonyl iron powder whose compositions are given in Table 5. The lowest wear rate is seen in Composition C2 whereas DCTs made by carbonyl iron powder as indicated by C4 shows high wear rate. All other tools were made by electrolytic iron powder.

3.3 Relative performance of DCTs made using Electrolytic iron powder

Table 5 shows detail summary of the properties of DCTs made using electrolytic iron powder. The wear rates of different compositions of DCTs tried in the present work are shown in Fig.7.

Table 5: Hot-pressed sintered properties of diamond cutting tools

*Comp. No.	Sample Coding	850 °C			900 °C			950 °C		
		Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)	Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)	Hardness HRB	Density (g/cc)	**Wear Rate (mm^3/m)
C1	Base +Ni	103	7.13	4.126E-04	109	7.11	4.477E-04	Not Done		
C2	Base+Ni+D	103	6.88	0.29E-04	102	7.04	3.551E-04	Not Done		
C3	Base +Ni (C-Fe)	106	7.56	10.3E-04	109	7.59	12.2E-04	Not Done		
C4	Base+Ni+D (C-Fe)	106	7.32	9.34E-04	107	7.36	5.20E-04	Not Done		
C5	Base +Ni +D+ Sn	111	7.11	1.481E-04	108	7.30	2.65E-04	Not Done		
C6	Base +Ni + Sn Al, Mg Not Added	101	8.26	10.78E-04	Not Done			Not Done		
C7	Base +Ni + Sn+ D Al, Mg Not Added	101	7.9	4.22E-04	Not Done			Not Done		
C8	Ni Free Base	108	7.09	9.669E-04	111	7.15	4.460E-04	106	7.45	12.32E-04
C9	Ni Free Base + Sn	115	7.33	4.790E-04	109	7.47	4.25E-04	Not Done		
C10	Ni Free Base + D	106	7.03	2.019E-04	108	7.14	2.151E-04	104	7.29	3.532E-04

All compositions except 6 & 7 contain Al, Mg invariably.

*N.B: D = Diamond reinforced, Ni = Nickel 2%, Sn = Tin 2%, Base = without diamond, Ni-free: Nickel not added, FTC=Fused tungsten carbide.*Refer Table 2 for detail compositions.*

***Parameters for wear test are - Load = 2kg, Pressure= 0.4 MPa, Velocity= 2.34 m/s.*

All hardness and wear rate values were calculated with the average of 6 readings with error of ±3 HRB and ± 15% respectively.

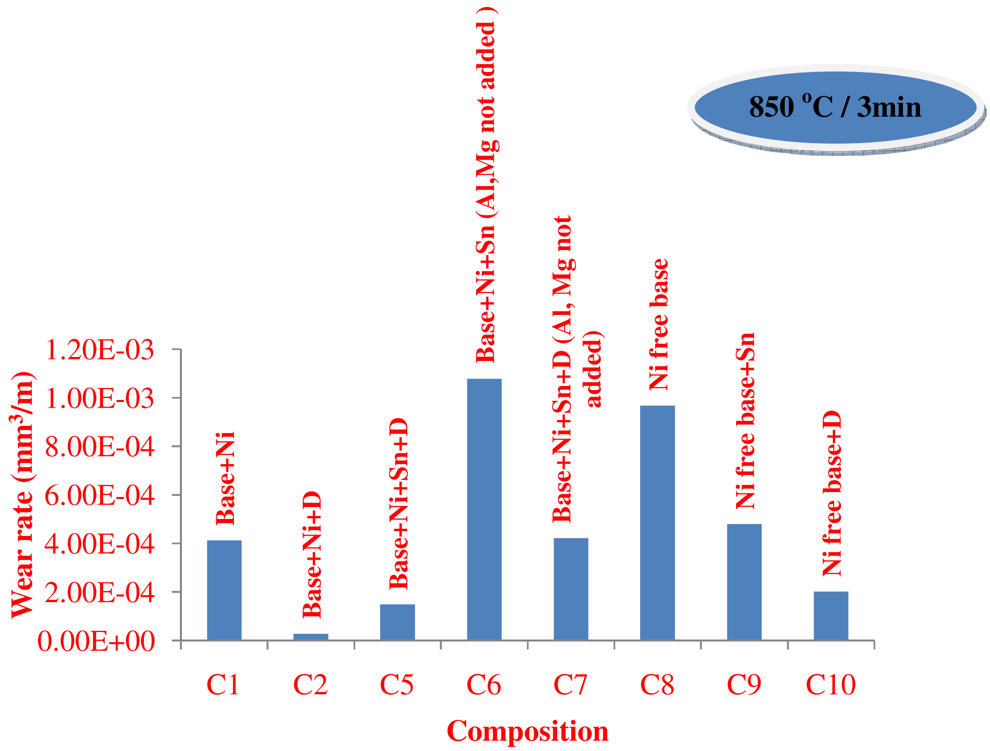
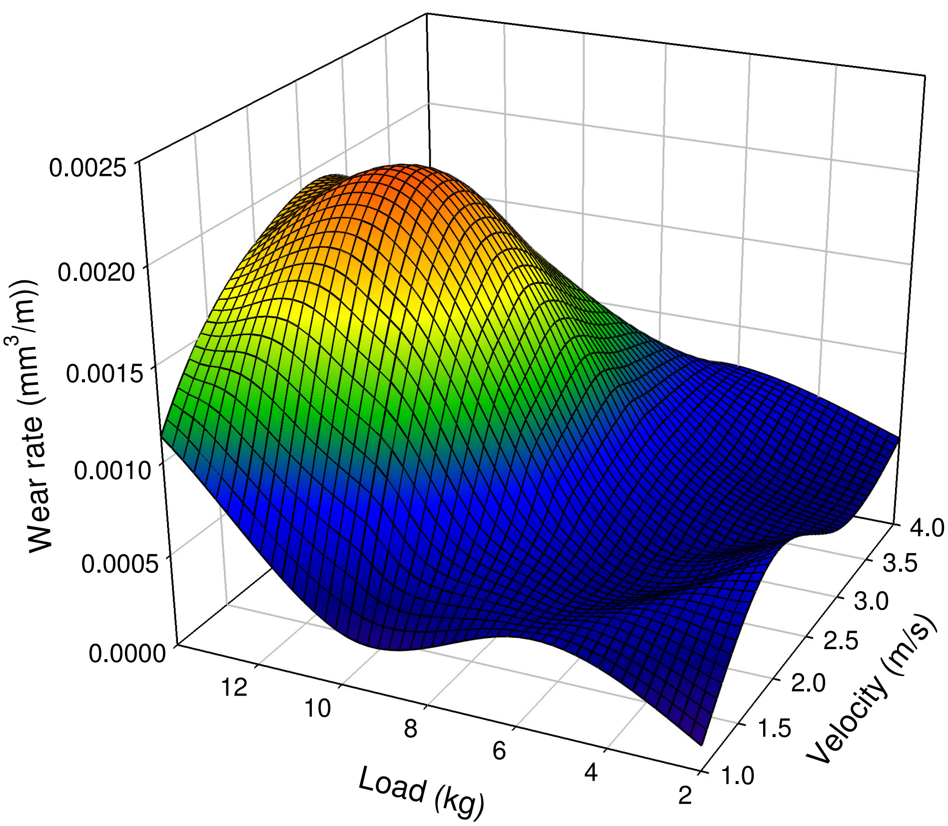


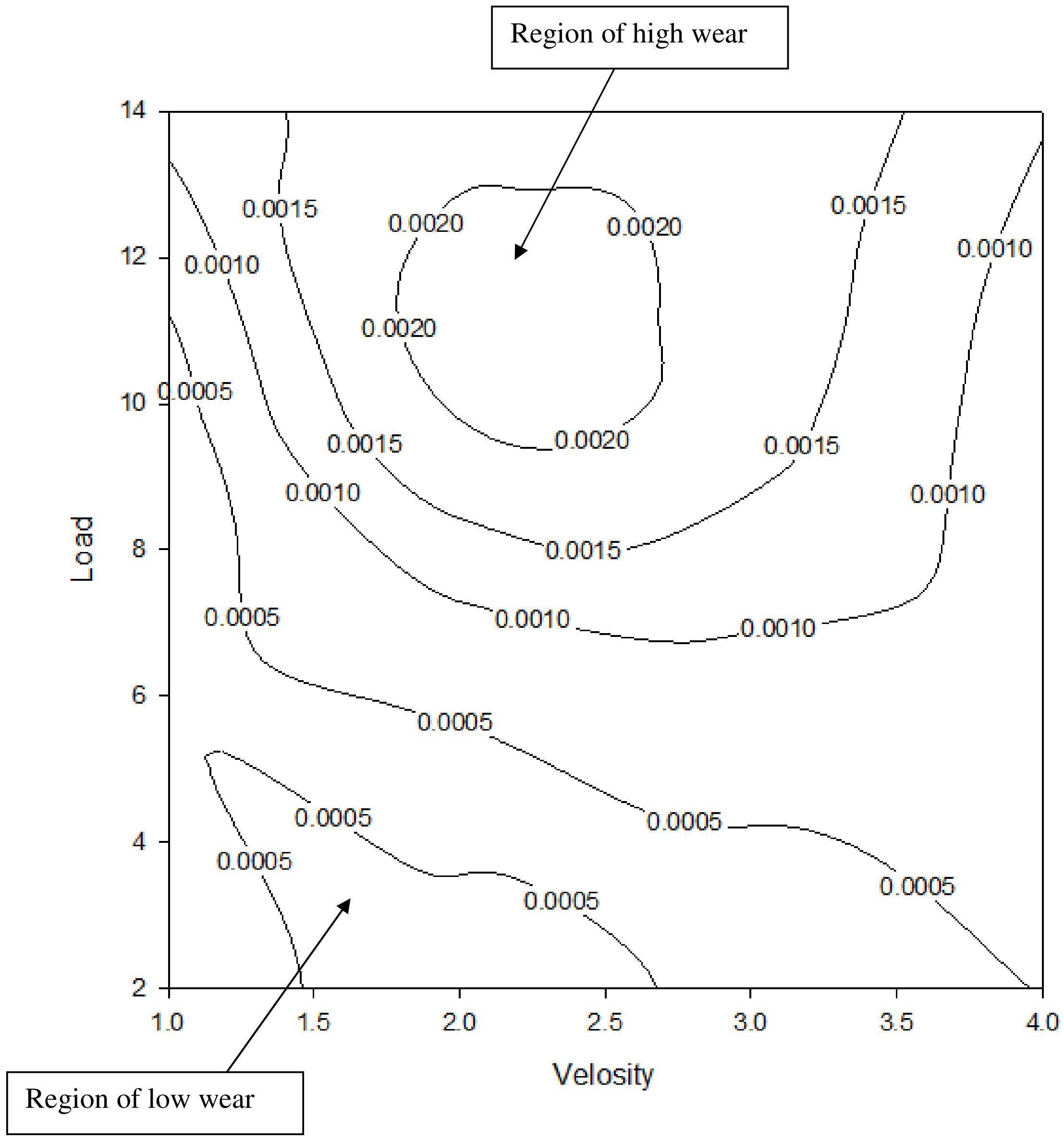
Fig. 7: Wear rates of diamond cutting tools made using Electrolytic iron powder (Refer Table-2 for compositions)

3.4 Wear mapping of DCT (C-10)

The DCT of composition C10 was used to study the effect of load and velocity on the wear rates. The extreme values of loads and varying velocity were employed. The 3D graph and the contour are plotted using wear test data as indicated in Fig.8.The excellent performance is shown by DCTs upto 6 kg load and for all velocities attempted. Beyond 6 kg, there is severe wear of DCTs is noticed. Thus 2D contour can help engineer to select operating variables during cutting operations of marbles /stones when one has to work in optimum wear condition of the diamond cutting tools.



(a) 3D surface response



(b) 2 D contour map drawn from 3 D plot

Fig. 8: 3 D surface response for DCTs of C10 (a) and 2D contour (b)

4. Conclusions

1) Electrolytic iron gives higher hot pressed hardness than carbonyl iron.
2) DCT containing electrolytic iron powder gives higher wear resistance.
3) Successful replacement of carbonyl iron by TR grade powder.
4) The wear rate of DCTs increases with the addition of Ni, Sn, Al, and Mg.
5) However their addition causes slight increase in the hardness and density.
6) Higher wear rate was observed at the higher load.
7) The diamond gets graphitized and fractured at the high temperature (above 900 ^{o}C) causing excess wear rate of DCTs. Thus the sintering temperature in the range of 850 – 900 ^{o}C is better in the manufacturing of DCTs.