23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

ANALYSIS OF MULTIPLE COMPARISONS TEST ON INFLUENCE OF TWIST DRILL CARBIDE COATINGS AT THE CUTTING FORCE OF DRILLING COMPACTED GRAPHITE IRON

Deibe Valgas dos Santos
[1]Centro Universitário UNA; Av. Afonso Vaz de Melo, 465, Barreiro, CEP:30640-070 Belo Horizonte - MG
deibe.santos@prof.una.br[1]

Durval Uchôas Braga
[2]Universidade Federal de São João Del Rei (UFSJ); Departamento de Engenharia Mecânica. Praça Frei Orlado, 170 Centro, CEP: 36307-352 São João del Rei - MG
durval@ufsj.edu.br[2]

Elifas Levi da Silva
[3] Centro Universitário de Formiga (UNIFOR); Av. Doutor Arnaldo Sena, 328, Água Vermelha, CEP: 35570-000 Formiga - MG
elifas.silva@usiminas.com[3]

Abstract. *The multiple comparison test permit to identify the differences between specific pairs of averages or averages of the linear combinations. This research aimed to evaluate the influence of the twist drills carbide coatings on cutting forces in drilling Compacted Graphite Iron (ASTM A 842/2004), which is used in building components for automotive. The input variables of this study was the feed per revolution of 26 mm/rev. and cutting speed of 90 m/min, and three twist drill carbide of 10 mm diameter with the same geometry. The tests were realized with external coolant spouted and dry, used three routes with the depth of the 10, 20 and 30mm. The process responses were torque value, feed force and the average roughness (Ra) and maximum (Rz). The Plan of experimental followed the full factorial statistical model, including two levels for coolant, and three levels for the coatings and three levels for the drill feed, was used the contrast test to check for statistical difference between the average of the torque value and the drill feed. As possible results, there is the coolant influences the cutting forces represented by the torque value, also in feed force. For the torque value, the type of coating showed no statistically influence, however, for the feed force coating AlCrN+y showed the greatest cutting forces.*

Keywords: *Compacted Graphite Iron, Coatings, Drilling, Multiple Comparison Test*

1. INTRODUCTION

The existing fierce competition between companies and the impositions of consumers for the final product, it is necessary to search for flexibility and agility in manufacturing processes, aggregate cost reduction in product manufacturing. Researches of materials are essential to meet the desired requirements of innovative products and also understanding the behavior of these materials in the processes that are intended according to their functionality.

As pointed out by Diniz, et al., (2013), among the main processes to which they can submit these materials, drilling has its highlight. The holes can be made that vary in dimensions from a few millimeters up to several centimeters diameter, depending on the cutting tool, which in this case is a two-lipped cutter tool. The tool or the workpiece moves according to a rectilinear trajectory coinciding or parallel to the machine axis. Reported by Castillo (2005) the drilling process represents a significant portion in the manufacturing process, involving 30% of the total application in the machining process industry, in view of this, it is important to have a focused attention to research in this area, aimed at improving the understanding and the conjecture of the phenomena that happens in it.

The drilling in diesel engine blocks has a number of quite significant holes, it is worth mentioning the work of Andrade (2005), which through their research points out that the compacted graphite iron, known as Compacted Graphite Iron or (CGI), it has been highlighted as the replacement materials that are used in the manufacture of engine blocks, especially diesel. However, despite the CGI have good mechanical properties and the various benefits that brings, it has a metallurgical structure of difficult to machine, and this aspect of the negative element in your application. Another aspect raised by Guesser (2009) is the biggest setback in the machining of compacted graphite iron compared to gray cast iron is linked to two main factors, which are due to its high mechanical strength, prompting large cutting forces in operations of machining, and the shortage of manganese sulfide in their microstructure, element that is constantly present in the gray cast iron, and who sits on the cutting tool and ensures the local lubricant action.

When referring to this subject, Almeida (2008) shows in his research that the coatings are presented as important elements in tool life, and, TiAlN (titanium aluminum nitride) a coating widely used in tools for machining cast iron, mainly in drilling. TiAlN is characterized by the hot hardness in machining, and helps reduce the friction piece and tool. According to studies related to machining, oxidation occurring on the coating surface, to produce Al_2O_3 (aluminum oxide), keeping the hardness of the coating even at high temperatures, and thus increasing wear resistance arises.

Machado, et al., (2011) emphasizes that the phenomena of the machining process that should have greater attention, it is the understanding of the cutting tool life or effective cutting time. Also in this same line of considerations, the parameter that has most influence on tool life is cutting speed in the form of tool wear, and being the main factor responsible for the increase in temperature in the cutting area, however, the coating of cutting tools may proportional one tool life increased while simultaneously reducing cutting forces.

This work has as purpose to evaluate the influence coatings drills TiAlN (Futura Top), AlCrN+x (Alcrona Pro), AlCrN+y (Helical) on cutting effort and roughness in the drilling of compacted graphite iron (CGI) in accordance with the ASTM 842/2004.

2. MATERIALS AND METHODS

2.1. Material

The material used in the tests was compacted graphite cast iron according to ASTM A 842/2004, the chemical composition was obtained by chemical analysis by Inductively Coupled Plasma (ICP) and infrared direct combustion. Table (2.1) shows the detailed chemical composition of the studied material, provided by Senai Laboratory Itaúna / MG.

Table 2.1: Chemical composition of compacted graphite iron.

Elements	Concentration %
Carbon (C)	3,5
Sulfur (S)	0,0145
Silicon (Si)	2,252
Manganese (Mn)	0,62
Magnesium (Mg)	0,012
Phosphorus (P)	0,083
Titanium (Ti)	0,046

For the tests we used the machining center ROMI, DISCOVERY 560 model, the dynamometer Kistler 9272. Figure 2.1 shows the Discovery machining center Romi 560, has a maximum available power of the spindle 15 kw, machine rotation is 10000 rpm. Figure 2.2 illustrates the stationary piezoelectric dynamometer four channels Kistler 9272, a signal amplifier 5070A Kistler and Dyno ware software also provided by the Kistler forces acquisition system comprising these devices was connected to a computer with Intel Pentium Dual Core 2.2 GHz with 2 GB of RAM.

Figure 2.1: Machining Center DISCOVERY 560 Romi

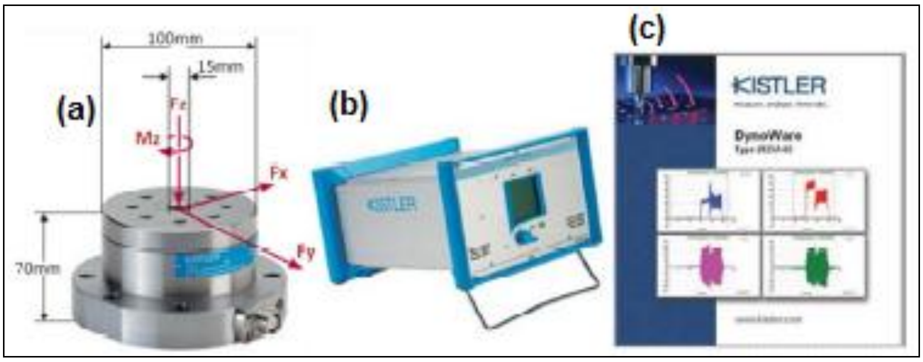

Figure 2.2: Assembly and dynamometer (a) Dynamometer Kistler 9272; (b) Charge amplifier Kistler 5070A; (c) software kistler DynoWare

They were used for three tests for carbide twist drills with diameter of 10 mm and the same geometry, each with a different coatings, which are (Alcrona Pro) AlCrN+x, (Futura top) TiAlN, and (Helical) AlCrN+y, the specification of twist drills used in drilling was R842-1000-30-A1A from the GC1210 class, the drills has a cutting edge angle κ_r of 70º and chamfered cutting edge with chamfer angle of 45º as shown in Fig. 2.3. The technology of coating studied twist drills were made through the process of Physical Vapour Deposition (PVD), the thickness of the coatings are 4 μm, the Alcrona Pro and Helical coatings them present a basic component that is an element that acts to reduce the friction between the coating and workpiece.

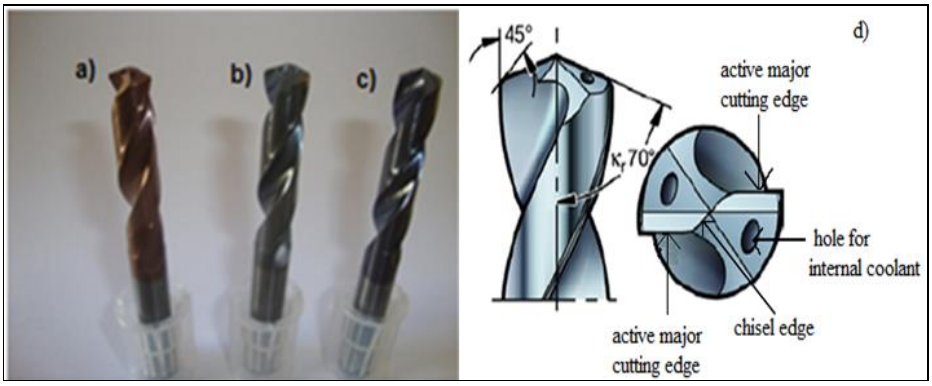

Figure 2.3: Drill carbide, a) (Hélica) AlCrN+y, b) (Futura top) TiAlN e c) (Alcrona Pro) AlCrN+x, d) Geometric specification of the twist drill used in the test

For drilling experiments we used the twist drill clamping system, the precision collet holders BT-40-DIN ISO 15488-C. Figure 2.4 illustrates the mounting fixation device used for twist drill with cylindrical shank - DIN 1835A and DIN 6535- HA. To monitor the maximum roughness (Rz) and average (Ra), the mounting scheme of such equipment may be seen in Fig. 2.5.

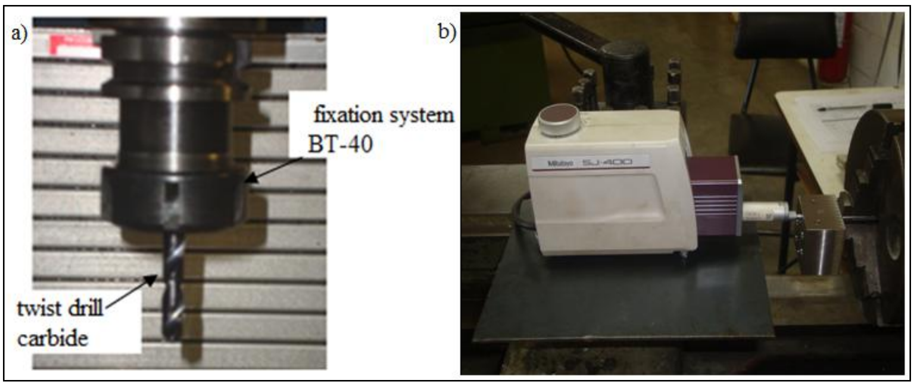

Figure 2.4: a) Mounting the precision collet holders BT-40 with the drill; b) Rugosimeter Surftest SJ-400 Mitutoyo

2.2. Methods

2.2.1. Plan of experiments

The Plan of experiments was designed as factorial statistical randomized by levels and fixed effect model (MONTGOMERY, 2003). For the variables of influence coatings the twist drills Carbide were selected in three levels being (AlCrN+y) Helical, (TiAlN) Futura Top and (AlCrN+x) Alcrona Pro and three replicas generating a total of 54 trial, and external coolant which are two levels with the oil emulsion Biodegradable BIO 100 E - shaped spouted, with 10% concentration and without external coolant, the length of the drill feed in three levels 10 mm, 20 mm and 30 mm. The Table (2.1), shows control variables used in this study and the response variables of the process are the torque value, feed force and average roughness (Ra) and maximum (Rz), with a 95% confidence level the results of the drilling compacted graphite iron, The control variables considered and their reference levels, were 0,26mm/rev. and feed per revolution, with a cutting speed of 90 m / min who show the Tab. 2.1.

Tabela 2.1: Control variables studied drilling process.

Control factors	Unit	levels	Specifications
Depth (i)	mm	3	10, 20 e 30
External coolant (j)	-	2	External coolant and Dry coolant
Feed per revolution	mm/rot	1	0,26
Cutting speed	m/min	1	90
Coatings carbide drills (k)	-	3	TiAlN AlCrN+x AlCrN+y

3. RESULTS AND DISCUSSION

The Table (3.1),(3.2) shows control variables used in this study and the response variables of the process are the torque value, feed force and average roughness (Ra) and maximum (Rz), with a 95% confidence level the results of the drilling vermicular cast iron.

Table 3.1: Mounting the Design of Experiments for the torque value.

Variable (i) - Depth = 3		Variable (j) - Coolant = 2					
Replies (n) n = 3		Variable (k) Coatings drills = 3					
Variable response							
Torque value (Nm)		TiAlN (k)					
		Coolant with			Coolant without		
Variable (i) - Depth	10	5,69	5,7	5,72	6,06	5,59	5,93
	20	5,88	5,77	5,80	6,35	5,68	6,31
	30	5,75	5,70	5,74	6,87	5,55	7,12
		AlCrN+x (k)					
		Coolant with			Coolant without		
	10	6,09	5,83	5,07	6,00	6,23	6,08
	20	6,16	5,87	5,72	6,12	6,52	6,23
	30	6,27	5,93	5,78	6,95	8,04	6,51
		AlCrN+y (k)					
		Coolant with			Coolant without		
	10	5,67	5,63	5,74	6,12	6,23	6,2
	20	5,55	5,60	5,70	6,27	6,34	6,36
	30	5,74	5,82	5,97	6,58	6,6	6,85

For the analysis of drill feed force results are shown in Tab. 2.3 which shows that the feed force was higher when not used external coolant next to 19,03 % especially the case where it is used drill AlCrN+y type.

Table 3.2: Mounting the Plan of Experiments for the feed force.

Variable (i) - Depth = 3			Variable (j) - Coolant = 2					
Replies (n) n = 3			Variable (k) Coatings drills = 3					
Variable response								
Feed force (N)			TiAlN (k)					
			Coolant with			Coolant without		
Variable (i) - Depth	10		1565	1596	1555	2008	1572	2037
	20		1552	1566	1567	2026	1601	2079
	30		1496	1499	1476	1931	1588	2007
			AlCrN+x (k)					
			Coolant with			Coolant without		
	10		1629	1541	1597	1918	1926	1951
	20		1606	1558	1565	1933	1960	1992
	30		1572	1530	1533	1929	1944	1897
			AlCrN+y (k)					
			Coolant with			Coolant without		
	10		1658	1631	1721	2020	2090	2139
	20		1635	1645	1644	2031	2104	2149
	30		1638	1655	1638	2008	2043	2065

The Table 3.1, shows that the torque value was larger (10%) when was not used cutting coolant. This can be explained by the reduction in lubrication between chips and the hole wall when machined without cutting coolant, It might therefore be observed that by the time difference torque value the end of the hole compared to the initial two-thirds of the drill feed by showing up even higher (5%), which justifies the friction largest chip flow in the flute drill. Can be identified in Tab. 3.1 that 15.3% of the effort generated by the torque value is given by the hole position and 36.5% cutting coolant and 6.4% of the interaction of cutting coolant and the hole position, that the length of feed (i) of the twist drill has no influence on the variation of the feed force, whereas the length of feed is the order of millimeters and the cutting length of meters. From Table 2.3, it is observed that drill AlCrN+y type was the one that had the highest feed force 8,33% compared with drill TiAlN and compared with AlCrN+y 5,77 %, for the case when used drill AlCrN+y type the increased feed force can be explained by the fact that the coating has a resistance to lower hardness than other coatings, thus, wear begins first in this drill increasing efforts cuts. When not using the external coolant in the drilling process the feed force increased by 19.03%.

Table 3.3 shows the analysis of influence of variables cutting coolant, the coating on the hole position about feed force, in the case of feed force the discussion becomes more complex because the spiral angle tends to act against the feed of the drill, relieving stress on the Kistler dynamometer.

.

Table 3.3: Table of Factorial design response.

Torque value (Nm)					
SS		GL			
SST	12,647			F calculated	F Tabled
SSi	1,941	2	F0i	8,572	3,259
SSj	4,623	1	F0j	40,844	4,113
SSk	0,492	2	F0k	2,173	3,259
SSij	0,822	2	F0ij	3,630	3,259
SSik	0,316	4	F0ik	0,697	2,634
SSjk	0,203	2	F0jk	0,896	3,259
SSijk	0,177	4	F0ijk	0,391	2,634
SSE	4,075	36			

Feed force (N)					
SS		GL			
SST	2561096,593			F calculated	F Tabled
SSi	20077,815	2	F0i	0,894	3,259
SSj	1881600,000	1	F0j	167,512	4,113
SSk	227350,704	2	F0k	10,120	3,259
SSij	3801,000	2	F0ij	0,169	3,259
SSik	3033,074	4	F0ik	0,068	2,634
SSjk	18230,333	2	F0jk	0,811	3,259
SSijk	2628,333	4	F0ijk	0,058	2,634
SSE	404375,333	36			

Roughness - Ra - (μm)					
SS		GL			
SST	259,416			F calculated	F Tabled
SSi	0,558	1	F0i	0,115	4,260
SSj	3,679	2	F0j	0,379	3,403
SSk	133,465	1	F0k	27,529	4,260
SSij	0,945	2	F0ij	0,097	3,403
SSik	1,363	1	F0ik	0,281	4,260
SSjk	1,939	2	F0jk	0,200	3,403
SSijk	1,111	2	F0ijk	0,115	3,403
SSE	116,357	24			

Roughness - Ry -(μm)					
SS		GL			
SST	192,184			F calculated	F Tabled
SSi	0,048	1	F0i	0,010	4,260
SSj	4,356	2	F0j	0,431	3,403
SSk	58,310	1	F0k	11,532	4,260
SSij	0,423	2	F0ij	0,042	3,403
SSik	3,813	1	F0ik	0,754	4,260
SSjk	2,169	2	F0jk	0,214	3,403
SSijk	1,717	2	F0ijk	0,170	3,403
SSE	121,348	24			

The multiple comparison test is a linear combination of totals that allows the comparison of treatment means (NEVES, 2003).The multiple comparison test (Contrast) was conducted to verify in case that there is significant difference of the mean torque value to the drill path length by testing it was found that there is a significant difference between the depths of 20 and 30 mm, and not no difference when the depth of 10 mm and 20 mm, this can be explained as follows, as the drill gets depth there is an increased friction between the wall of the hole with the drill guide, increasing torque value. Table 3.4 shows the results obtained by the multiple comparison test for hole position in relation to the torque value.

Table 3.4: Analysis for contrast influence of the hole position (i)

Contrast	C	SQ	GL	MQ	F calc.	F Tab	p-value	Decision
10mm x 20mm	2,65	0,195	1	0,2	1,72	4,11	0,2	not
30mm x 20mm	5,54	0,853	1	0,85	7,53	4,11	0,01	yes

The effect of the AlCrN+y drill has proved different from the others when evaluated in contrast statistical test, as Tab. 3.5, and the AlCrN+y drill was showed the most effort in relation to the feed force.

Table 3.5: Contrast analysis to influence coatings (k)

Contrast	C	MQ	GL	F calc.	F Tab	p-value	Decision
TiAlN * AlCrN+x	860	20544	1	1,83	4,11	0,18	not
AlCrN+x * AlCrN+y	1933	103791	1	9,24	4,11	0,00	yes

It was observed for the beginning of the hole, a higher level of roughness when not in use cutting coolant indepedent of the type of coatings of the drill. This is explained by higher cutting forces, indirectly presented by torque value, with more deflection drill this cutting condition.

Another observation related the maximum roughness (Rz), which showed less residue when compared to average roughness (Ra). This fact can be explained by the smoothing effect of the active minor cutting edge and drill guide in the hole surface.

4. CONCLUSION

It was observed that the type of tool coatings did not affect the torque value the conditions of the tests, nevertheless, the torque value was larger at the end of the hole especially the case when not used external coolant. Through the statistic model there is no interaction between the type of drill, the cutting coolant and the drill path length with respect to the monitored feed force.

It might therefore be concluded by the difference torque value the end of the hole compared to the initial two-thirds of the drill feed, showing up even higher 5%.

It was concluded that the feed force was higher when not used external coolant next to 19.03% especially the case where it is used drill AlCrN+y type, in the case of drills TiAlN and AlCrN+x coating showed no differences in the monitored feed force,

The investigations of feed force the drill AlCrN+y type to showed increased by 8.33% compared with the drill TiAlN and 5, 77 % compared with the drill AlCrN+x.

In the test made in this study it was identified that independent of the drill without cutting coolant drilling condition showed the highest average roughness (Ra) and maximum (Rz) of the hole surface.

5. ACKNOWLEDGEMENTS

The authors acknowledge the assistance of DEMEC/UFSJ and SENAI-CETEF/Itauna for the donation of compacted graphite cast iron plates, the SANDVIK OF BRAZIL SA for drills and OERRLIKON BALZERS BRAZIL for the coatings in Twist drills, and FAPEMIG, the University Center UNA and the University Center Formiga for supporting this research.

6. REFERENCES

Almeida, Déborah Oliveira. *Investigação de desvios geométricos no alargamento de ferro fundido vermicular com ferramentas revestidas*. 2008.100f. Dissertação (Mestrado) - Curso de Engenharia Mecânica, Departamento de Engenharia Mecânica, Universidade Federal de Uberlândia, Uberlândia, 2008.

Andrade, C.L. *Análise da Furação do Ferro Fundido Vermicular com Brocas de Metal-Duro com Canais Retos Revestidas com TiN e TiAlN*. Florianópolis, 2005. Dissertação Departamento de Engenharia Mecânica, Universidade Federal de Santa Catarina.

Castillo, Willian Jefferson González. *Furação profunda de ferro fundido cinzento GG25 com brocas de Metal-Duro com canais retos*. 2005. 134 f. Dissertação (Mestrado) - Curso de Engenharia Mecânica, Programa de Pós–graduação em Engenharia Mecânica, Universidade Federal de Santa Catarina, Florianópolis, 2005. Disponível em: <http://livros01.livrosgratis.com.br/cp078285.pdf>. Acesso em: 20 Dez. 2014.

Diniz, Anselmo Eduardo; MARCONDES, Francisco Carlos; COPPINI, Nivaldo Lemos. *Tecnologia da Usinagem dos Materiais*. 8ª edição. São Paulo: Artliber, 2013. 262 p.

Guesser, W. L. *Propriedade Mecânica dos Ferros Fundidos*. 1ª Edição São Paulo, SP: Editora Blucher, 2009. 336 p.

Montgomery, D. C.; R. G. C. *Estatística Aplicada e Probabilidade para Engenheiros*. Rio de Janeiro: LTC Livros Técnicos Editora S. A., 2003, 496p.

Machado, Á. R. ; ABRÃO, A. M. ; COELHO, R. T. ; DA SILVA, M. B. *Teoria da Usinagem dos Materiais*. 1. ed. São Paulo - SP: Edgard Blucher, 2009. v. 1. 371 p.

Neves, Frederico Ozanan. Análise *das tensões residuais em tubos trefilados de aço inox ABNT 304*. Campinas: Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, 2003.141 p.Tese (Doutorado).

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.