MECHANICAL AND GEOLOGICAL INFLUENCES ON DRILLING LIMESTONE ROCK AT LOW ROTARY SPEED

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The drillability of a rock mass is determined by various geological and mechanical parameters. In this study some major correlations between specific geological factors and drilling rate are shown. Drilling rate is dependent on a lot of geological parameters which include jointing of rock mass, orientation of schistosity (rock anisotropy), degree of interlocking of microstructures, porosity and quality cementation in clastic rock, degree of hydrothermal decomposition and weathering of a rock mass.

Three types of limestone rocks were drilled by diamond core bit using a fixed laboratory-diamond drilling machine at 400 rotational speed, and over a range of weights on bit (WOB) 15,30,45,……,150 kg. Operating parameters of the drill bit such as WOB, rate of penetration (ROP), torque and drilling specific energy (SE) were continuously monitored during the drilling trials. The effects of these parameters on the performance of the bit were examined. Relationships between WOB and both ROP, torque and SE were also described and the relationship between ROP and SE, was also given. Simple graphs are presented which can be used to predict diamond-drilling performance easy and fast.

INTRODUCTION

Drilling is an essential and integral process of mineral exploration to present a clear picture of extent of any ore body, its mineral content, the stratigraphy or to confirm any geological or indirect geological interpretations of what is lying below the earth's surface. The type of strata and structure to be drilled has a significant influence on the drilling performance of a bit. Resistance to penetration, resistance to shearing action of the bit in rotation and the degree of abrasiveness are the properties that would be expected to have the greatest influences [1, 2].

Drilling rate is one of the main factors affecting drilling cost. The overall performance of any drill bit is complex and is affected by numerous factors which include operating parameters of the bit, formation properties, bit design and type, wear characteristics, drilling fluid properties and flow mechanics, hole characteristics, capacity of the drilling machine, time, climate and operator or crew efficiency. However, the principal factors that are required in predicting drilling rates are the operating parameters of the drill bits and the penetrated rock characteristics. [3, 4]

In this work diamond drilling machine was used to obtain cores from three types of limestone formation of different properties. The three types of rock were obtained from the Assiut cement company quarries, Egypt. The inside diameter of the

bit used is 40 mm and the outside is 45 mm and the bit has four water way. All drilling trails were carried out at approximately 400 Revolution per minute value was Therefore, the bit has a set of drilling data for the rocks, at a particular RPM and applied weight on bit. A total of 50 drilling tests have been completed and a total of 5m has been drilled. [4]

Geological difficulties may have a high impact on the economics of underground construction project, especially when the chosen excavation system turns out to be unsuitable for the conditions encountered. Thus it can be argued that the geological and petrological characteristics of the rock mass should be evaluated with the same degree of effort as that for the geotechnical prognosis. [5, 6]

The objective of this work is to study influence of the mechanical parameters of the diamond core bit such as weight on the bit, fixed rotary speed, drilling specific energy on the rate of penetration. Studying the effect of geological factors (composition, bedding, and minor structure) on the penetration rate in different limestone rocks.

GEOLOGICAL SETTING

The Assiut region of middle Egypt may as a preliminary approximation can be regarded as representative of the general structural style of the (stable) paleogeographic and structural domain of the Arabian Nubian shelf, bounded to the northwest by the mobile zone of the unstable shelf. It comprises the plateau which forms the mesa west and east of the Nile mesa (the western and eastern deserts). Wadi el Assiuty Eocene plateau bounding the Nile valley near Assiut is composed of limestone (Drunka formation) which is quarried for Cement industry.

The topmost levels of the scarp exhibit clear karstification with fillings rich in iron oxide (.it was in post –early Eocene timed that the southern parts of Egypt were uplifted and the sea regressed to the north. Since then that plateau in this particular area was never covered by any marine invasion. Erosion took place, especially in Oligocene and later times leaving its imprints in the form of piles of the gravels, forming conglomerates. As well as karstified limestone beds, most of the scarps around Assiut show such phenomena [7]

Please note the limited lateral extension of the red –colored fillings parallel to bedding and the clear vertical passages of the solution along joints Fig (5).

TESTED ROCKS

PETROGRAPHY OF LIMESTONE SAMPLES

a)- Fresh Limestone (Rock 1) (Bioturbated Limestone to Wakestone):

These types white-grey in color and very fine fragment of limestone components from nummulites, green algae, and miliolidae foraminifera with some Bioclasts of unknown origin. Fig (1, 2,)

b)- Bedded Limestone (Rock 2) (Bioclastic Wakestone to Pakestone) :

It is white Brownish in color, very fine limestone and thin bedded composed of very fine sand size to silt Bioclasts of uncertain origin and rare-quartz silt with very thin layer from iron oxides. Fig (3, 4)

c)- Non-Fresh Limestone (Rock 3) (Lithoclastic Fossiliferous Floatstone) :

It is white-brown containing patches from iron oxides and quartz of pink color composed mainly of coarse to medium grain size of limestone (Lithoclastes, Erchinodermal frag , Nummulites , bryozoa , Green algae and fragments of unknown origin), euhedral colours from calcite and low interference color, fragment of non-hedral crystal from quartz and fine disseminated non-hedral iron oxide. Fig (5, 6)

Fig (1) showing core and sample from fresh limestone

Fig (2)   Aphoto micrograph of fresh limestone showing the very fine limestone and rare-quartz silts. (5 x 10)

Fig (3): showing core and sample from Bedding limestone

Fig (4) Aphotomicrograph of bedded limestone showing the bedding and the different between of grain size of limestone in two bed. (5 x 10)

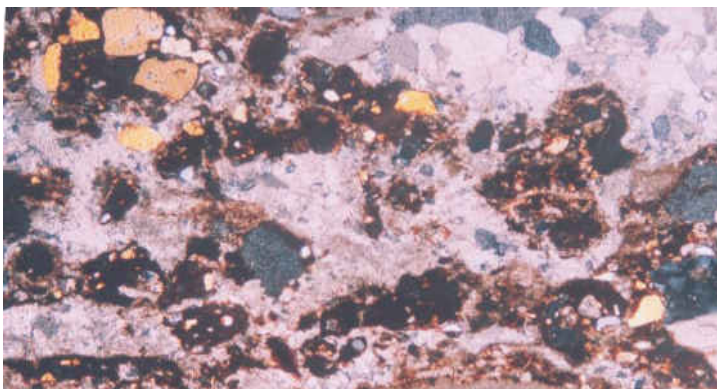Fig.(5) : showing core and sample from Limestone with interfaces

Fig (6) Aphotomicrograph of the non-fresh limestone under crossed-nicoles showing
Iron oxides (Dark colour) , Quartz (yellow and grey) in limestone (2.5 x 10)

PROPERTIES OF THE TESTED ROCKS

The most important physical and mechanical properties of the tested rocks such as density, porosity, compressive strength, tensile strength, and coefficient of internal friction (μ) were determined. Table (1) contains the average value for each test together with its stander deviation. The rocks were choose as a testing medium because they represent a range of limestone rocks, in terms of strength, for mining and civil engineering.

Table (1) :The final values of physical and mechanical properties of the tested rocks.

Rock type	Compressive strength,MPa	Tensile strength,MPa	Density,g/cc	Porosity,%	Coefficient of friction.
Rock 1	137.8±11.57	17.14±1.2	2.06±0.032	12.87±o.94	0.95
Rock 2	271.82±9.97	36.4±0.66	2.30±0.030	9.06.1±0.72	1.02
Rock 3.	259.01±15.1	27.41±1.79	2.42±0.009	6.83±0.21	1.03

EXPERIMENTAL WORK

In the present study, blocks are formed by diamond saw from each type of rock for the drilling test. Diamond core drilling is applied for the tests.. The drilling machine is a fixed laboratory type [8].

Data and conditions of drilling experiments and rocks under test were recorded. Applied load, actual speed, length of borehole, time of drilling are recorded as results of drilling. This result is used to calculate the drilling rate, and the average drilling rate at a specific load. Three trials were carried out for a particular weight on

bit (WOB). Selection of the WOB range for the bit was made by applying minimum WOB where the bit was just capable of drilling the rock and maximum WOB just below the point where the drill commenced to stall or showed "distressed" drilling. Ten WOB increments for each rock were selected between these limit. All drilling trials were carried out at 400, rpm motor speed. The rpm value was at the unloaded speed. However, the speed reduced over a small range with increasing torque. The experimental data of the operating parameters are presented in Table (2).

Table (2)- Experimental data for the operating parameters of the core drilling.

WOB,	Fresh limestone (Rock1)			Bedded limestone (Rock 2)			Non fresh limestone (Rock 3)		
Kg	ROP, mm/min	Torque, Nm	SE, MPa	ROP, mm/min	Torque, Nm	SE MPa	ROP, mm/min	Torque, Nm	SE, MPa
15	0.14	3.17	3576.58	-	-	-	-	-	-
30	2.07	6.34	483.677	-	-	-	0.0895	6.88	12139.54
45	2.58	9.51	582.100	0.30	10.21	5374.54	0.152	10.31	10711.55
60	3.2	12.68	625.758	0.50	13.62	4301.74	0.218	13.75	9960.55
75	2.5	15.85	1001.21	0.52	17.02	5168.84	0.2905	17.19	9344.73
90	2.5	19.02	1201.46	0.72	20.43	4480.98	0.492	20.63	6621.73
105	1.9	22.19	1844.33	0.75	23.83	4807.08	0.6063	24.06	6266.79
120	-	-	-	0.95	27.23	4526.49	0.7408	27.50	5862.31
135	-	-	-	0.85	30.64	5692.55	0.5966	30.94	8189.82
150	-	-	-	-	-	-	0.7378	34.37	7356.61

RESULTS AND DISCUSSION

Effects of both weight on bit (WOB), rotary speed (RPM), and the geological parameters on rate of penetration are discussed below:

MECHANICAL PARAMETERS

a) **Effect of WOB on rate of penetration:** Effect of weight on bit (WOB) on the rate of penetration (ROP) is given in fig. (7). It is clear that, the increasing of the weight on bit (WOB) produces an increase in the rate of penetration (ROP) up to a maximum point. However, from the experimental data a further increase in weight on bit (WOB) causes little increase, or even a decrease in the rate of penetration (ROP) as in the case of drilling fresh limestone.

The optimum load (WOB) is the weight which gives maximum value of the penetration rate (ROP) for rock drilling. From fig (7) for Fresh limestone, the best weight on bit is 60 kg, that gives maximum value of rate of penetration (ROP=3.2 mm/min.), for bedded and non fresh limestone, the best weight on bit is 120 kg, that gives maximum value of rate of penetration (0.95mm/min) and 0.75 mm/min) respectively.

At 60 kg WOB, the rate of penetration in fresh limestone is about 6and 9 times more than of the bedded and non fresh limestone respectively Fig (7).
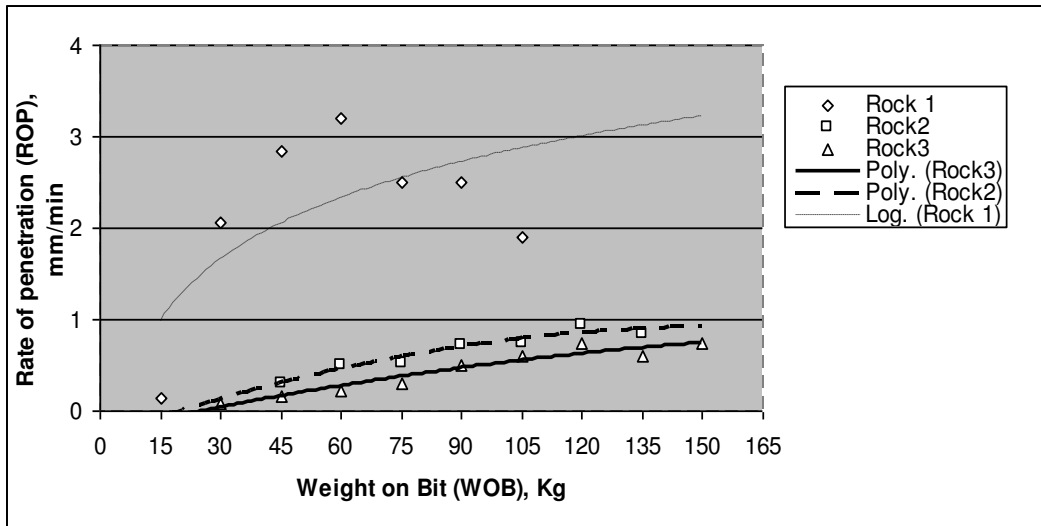
Fig. (7) Relation between (WOB) and (ROP) for the tested rocks.

b) Effect of both weight on bit, and, rotary speed on torque:

The torque is a measure of resistive forces opposing rotation and is a function of friction, cutting or shearing forces and abrasion at the bit/rock interface. Hence with increasing WOB the friction resistance is increased and required greater torque, being dependent upon the strength of the rock [9].

There is a linear relation between the two parameters (WOB & T) up to the critical value or stalling conditions, the rate of penetration rises with increasing weight on bit WOB. Figures (8) show the relations between weight on bit (WOB) and torque (T) of the fresh lime stone as an example.
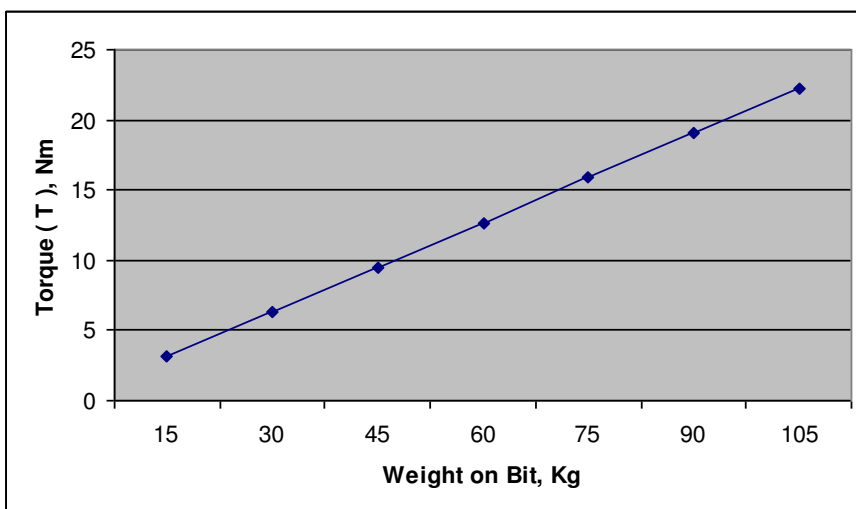

Fig. (8) Relation between (WOB) and (T) for rock (1).

c) Relationship between WOB and specific energy (SE):

A very good indication of how well a bit performing in a particular rock formation is given by a study of the drilling specific energy. Specific energy (SE) may be defined, as the energy required for removing a unit volume of rock; it may use any consistent set of units [10, 11 &12]

Fig.(9) shows that at low WOB, SE increases for the three types of rock and increasing WOB is associated by decreasing in SE for a certain limits, then decreasing WOB increases SE. WOB that gives the lower value of the SE is the optimum WOB. From the results and Fig.(9) it can be seen that the optimum WOB is 30 kg for drilling in Fresh limestone, 60 kg for drilling in Bedded limestone and 120 kg for drilling in Non-Fresh Limestone.

d) Relation between (ROP) and (S.E).

From fig.(10),(11) and (12) ,it can be seen that S.E is proportional inversely with ROP in all tested rocks. As stated before, the highest values of penetration rate for drilling in rock (1), rock (2) and rock (3) were 3.2, 0.95, and 0.75 mm/min respectively. On the other hand the corresponding values of SE were 625.758, 4226.49 and 5862.31 MPa for the three rocks respectively. Then, the machine consumes energy 9 and 6 times more in drilling non fresh limestone and bedded limestone than that in drilling fresh limestone and the energy consumption was 1.3 times more in drilling non fresh limestone than that in drilling bedded limestone.
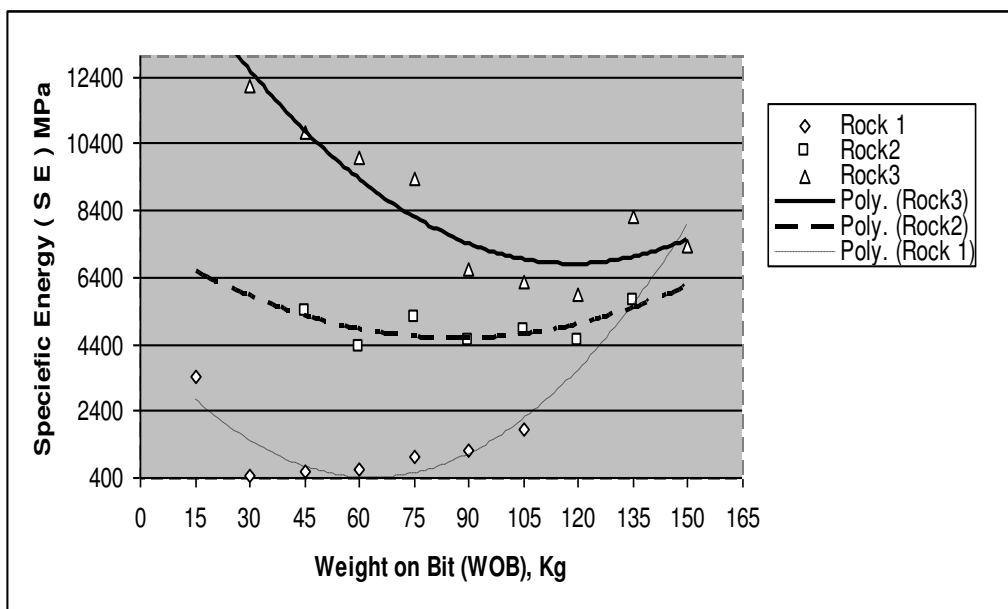

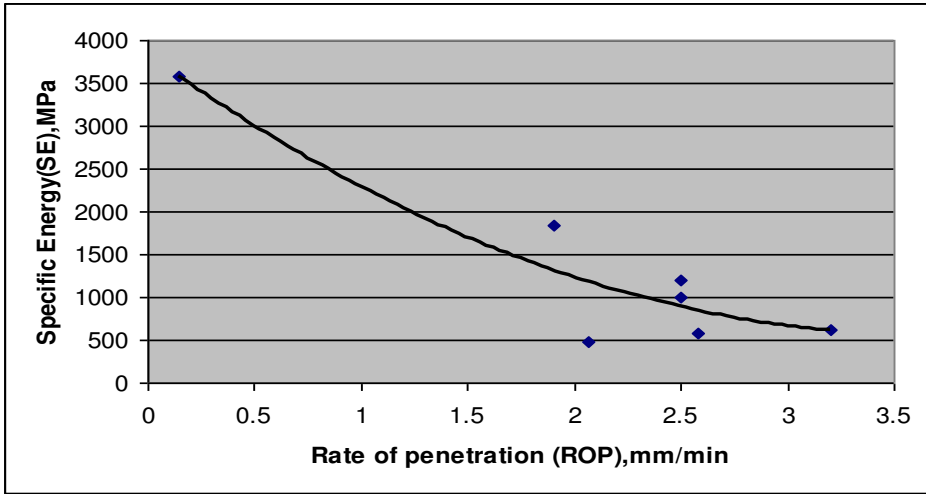Fig. (9) Relation between (WOB) and (S.E) for tested rocks.

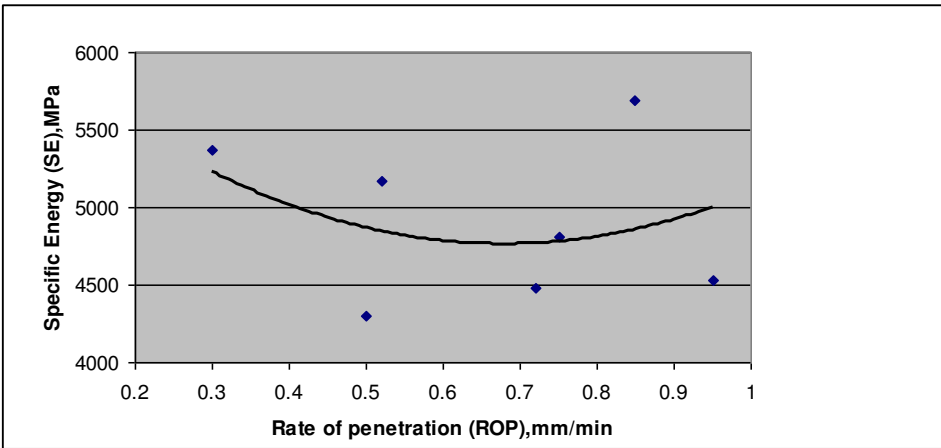Fig. (10) Relation between (ROP) and (S.E) for rock (1).

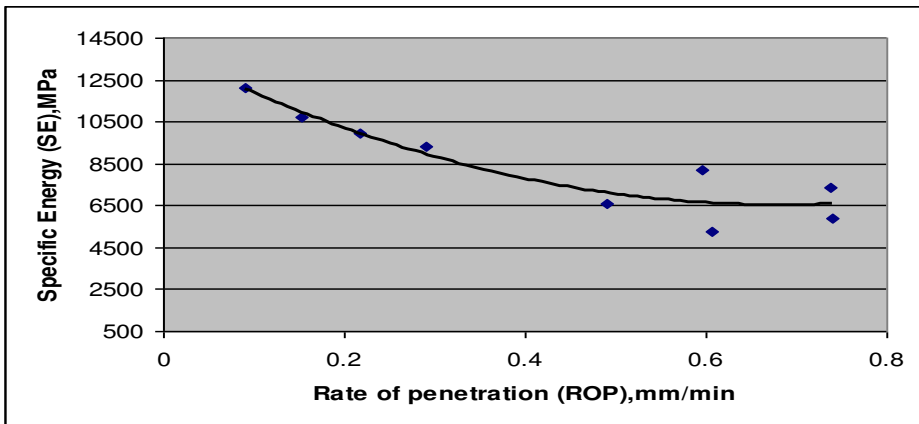Fig. (11) Relation between (ROP) and (S.E) for rock (2).

Fig. (12) Relation between (ROP) and (S.E) for rock (3).

GEOLOGICAL PARAMETERS:

It is clear, that the drilling parameters and tool wear are predominantly a result of the mineral content harder than steel, especially quartz, calcite and iron oxide, which decrease the rate of penetration, Accordingly we found the highest penetration rate is in Fresh limestone as it contains the lowest iron oxide and quartz, and Non-Fresh Limestone has the lowest penetration rate, because it contains the low percentage of quartz and calcite. By the same way we predicted that Bedded limestone is lower than Non-Fresh Limestone in penetration rate. But the experimental data show that it is higher than it, fig. (7), and that is because of bedding which is oriented parallel to drilling axis.

Porosity is measured here as a function of dry density of rock material. There seems to be a correlation between the porosity of the rock and technical parameters, such as drilling rates and - naturally -mechanical rock properties such as compressive strength. Accordingly we found that Fresh limestone has the highest penetration rate and porosity (12.86%), and the lowest compressive strength (137.8 kg/cm2). Where as Bedded limestone and non fresh limestone have low penetration rate and porosity (9.06% & 6.32%), and the high compressive strength (271.82 & 259.01 kg/cm2).

The size of grains affecting the penetration rate inversely, but in our case it's different, as there are other factors affecting the penetration rate ,such as cemented material which is weak in all types of tested rocks, the humidity content which is so high, anisotropy in Bedded limestone and the interferences in Non-Fresh Limestone, so that we found that Fresh limestone has a very fine grain size as shown as previously in fig.(1&2) ,but it has the highest penetration rate, and Bedded limestone has a medium grain size as shown as previously in fig.(3&4) and ,so it is lower than Fresh limestone in penetration rate ,and, higher than Non-Fresh Limestone which has the coarsest grain size fig.(5&6).

CONCLUSION

1- For drilling in fresh limestone, the optimum WOB that gives the maximum value of penetration rate was 60 Kg, where as 120 Kg was the optimum WOB that gives the best value of penetration rate for drilling bedded and non fresh limestone

2- There is a linear relationship between the two parameters (WOB & Torque) up to the critical value or stalling conditions, the rate of penetration rises with increasing weight on bit WOB.

3- At low WOB, SE increases for the three types of rock and the increase of WOB is associated by the decrease in SE for certain limits. Then, decreasing WOB increases SE. WOB that gives the lower value of the SE is the optimum WOB. From the results, it is found that the optimum WOB is 30 kg for drilling in fresh limestone and 60 kg for drilling in Bedded limestone and 120 kg for drilling in Non-Fresh Limestone.

4- The lower SE for drilling in fresh limestone was achieved at 30 Kg, where as it is achieved at 120 Kg for both bedded and non fresh limestone. Then the drilling machine needs SE about 10 times more to obtain the optimum ROP in cases of drilling bedded and non fresh limestone.

5- Fresh limestone has high penetration rate than both bedded and non fresh limestone because it contains the lowest percentage of iron oxide, quartz and calcite. Although bedded limestone has higher compressive strength and porosity than non fresh limestone, it has high ROP than it, that is because of bedding planes parallel to the drilling axis.

6- There was a correlation between the porosity of the rock and technical parameters. Accordingly we found that Fresh limestone has the highest ROP and porosity (12.86%), and the lowest compressive strength (137.8 kg/cm^2). Where as Bedded limestone and non fresh limestone have low penetration rate and porosity (9.06% & 6.32%), and the high compressive strength (271.82 & 259.01 kg/cm^2).

7- The size of grains affects the penetration rate inversely. But in our case it's different, as there are other factors affecting the penetration rate, such as the cementing material which is weak in all types of tested rocks, the humidity content which is so high, anisotropy in Bedded limestone and the interferences in Non-Fresh Limestone. So that we found that fresh limestone has a very fine grain size, but it has the highest penetration rate, and Bedded limestone has a medium grain size, so it is lower than Fresh limestone in penetration rate, and, higher than Non-Fresh Limestone which has the coarsest grain size.

REFERENCES

1. **Thuro. K.,** " Drillability prediction – geological influences in hard rock drill and blast tunneling " Geol. Rundsch Vol. 86: pp 426-438. 1997.

2. **El-Biblawi M. M., Sayed, M. A. Mostafa. T. M, and El-Rawy. W. R.**, " Some drilling parameters as a tool to predict different categories of rocks ",. Journal of engineering sciences, Assiut university, Vol. 35, No. 4, pp. 995-1008, July 2007

3. **Ersoy, A., and Waller, M. D**., "Drilling detritus and the operating parameters of thermally stable PDC core bits", Int. J. Rock Mech. & Min. Sci., Vol. 34, No. 7, Pp. 1109 – 1123, 1997.

4. **Sayed, M.A**., "Relation between operating parameters and bit performance in diamond core drilling", 7th International Conference on Mining, Petroleum and Metallurgical Engineering, 10-12 February, Assiut, Egypt, 2001.

5. **Schormair N., Thuro K. & Plinninger R.J., "**The influence of anisotropy on hard rock drilling and cutting" The geological society of London IAEG2006 paper Number 491.

6. **Thuro, K.,& Plinninger R.J.,**" Hard rock tunnel boring, cutting and blasting: rock parameters for excavatability ,In: Proceedings of the 10th ISRM International congress on Rock Mechanics, Johannesburg South Africa, 8-12, Septemper2003 , 1227-1234.

7. **Youssef M. M.., Philobbos E. R. and Bishara**. **W. W.** , " Geological studies on the sediment rocks along the Assiut – Kharga road " Workshop on Geoindications and their applications in arid region, Sept. 2003 Assiut university

8. **Imbaby, S.S.,** "Study of some factors affecting the drillability of rocks," M.Sc thesis, Faculty of Engineering, Assiut University, 1980.

9. **Chugh, C.P**., "High technology in drilling and and exploration " , A. A. Balkema, Rotterdam, 1992

10. **Rabia, H.,** "Specific energy as a criterion for bit selection ", Journal of Petroleum Technology, July 1985.
11. **Rowsell, P. T. and Waller, M. D.,** " Automatic optimization of rotary drilling parameters", 99, May – August, 1990.
12. **Teale, R.,** " The concept of specific energy in rock drilling ",. Int. J. Rock Mech. Min. Sci. 2, pp. 57-73, 1965.

تأثير العوامل الميكانيكية و الجيولوجية علي الحفر في صخور الحجر الجيري بسرعات حفر منخفضة

الهدف من البحث دراسة تاثيرالعوامل الميكانيكية والجيولوجية على الحفر في ثلاثة انواع من صخور الحجر الجيري المختلفة مثل الحجر الجيري النقي والحجر الجيري المحتوي على اكسيد الحديد والكوارتز والحجر الجيري الطباقي.

وقد تم اجراء الحفر على ثلاثة أنواع من صخور الحجر الجيري التي بها تباين في الخواص الجيولوجية بواسطة ماكينة حفر معملية ذات قواطع ماسية للثلاثة انواع عند سرعة منخفضة مقدارها 400 لفة/الدقيقةوتحت تاثير أوزان مختلفة تبدا من 15 كجم حتى 150 كجم.

أثناء اجراء التجارب تم قياس وتعيين بعض العوامل الخاصة بتشغيل ماكينة الحفر والتي لها تأثير على اداء القاطع مثل الحمل الواقع عليها و معدل الحفر و عزم الدوران والطاقة المستهلكة في عملية الحفر . وتم استنتاج علاقات بين الحمل الواقع على القاطع وكل من معدل الحفر وعزم الدوران والطاقة المستهلكة وكذلك تم استنتاج العلاقة بين معدل الحفر والطاقة المستهلكة للأنواع الثلاثة من الصخور .

واتضح من العلاقات السابقة تأثر معدلات الحفر و الطاقة المستهلكة بالعوامل الجيولوجية التي تم دراستها مثل التطابق والتركيب المعدني و المسامية و حجم الحبيبات لكل نوع من الصخور الثلاثة. ويمكن استخدام هذه العلاقات لتوقع أداء القاطع بسهولة ويسر .