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Flame Jet Burner Application and Performance characteristics in Cutting Miya Granite for Dimension Stone

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***Abstract*— This work examines the application and performance characteristics of FA300A flame jet burner in cutting Miya granite for dimension stone. The application procedures involves preparation to start flame jet cutting by removal of overburden, boulders and other impurities using bulldozer, payloader and compressed air, respectively. Furthermore, ignition of the flame jet burner involves combustion of diesel gas at appropriate time using acetylene gas and oxygen as well as compressed air. The flame jet cutting operation utilized continuous heating of rock to its spallation until flakes are formed from the surface of granite kerf. Performance test of flame jet burner in cutting Miya granite for dimension stone were conducted with reference to actual cutting speed, heat release rate, penetration rate and productivity. The heat input of the flame jet burner was determined to be 483.1 kW resulting in heat release rate per unit internal cross sectional area of the burner as 680,433.5 kW/m^2 while heat release rate per unit volume of flame jet burner was 1, 134, 038 kW/m^3. The penetration rate of 0.4 mm/s was obtained when FA300A flame jet burner was applied to cut Miya granite for dimension stone. The flame jet burner had cutting speed of 1.65 m^2/hr and productivity of 16.6 kg/m^2.s in cutting Miya granite for dimension stone. Also highlighted were operating parameters of the flame jet burner that must be kept in mind for its improved adaptation in Nigerian mineral extractive industry.**

***Index Terms*— Combustion, Dimension stone, Flame jet burner, Performance test**

I. INTRODUCTION

Flame jet burner application in cutting granite for dimension stone is an example of an industrial combustion applications due to its simplicity, flexibility and high heat transfer intensity. Heat transfer in turbulent non-premixed jet flames are highly radiating, an attribute desired in heating granite to spallation. Flame jet is a concentrated flame stream of burning fuel and air that is forced under pressure from a nozzle in a combustion chamber with capacity to cut or divide materials into specific size in one or more directions such as length, width and height. Flame jet burner is a high temperature and heating device also used in glass processing industry for cutting of glass products due to its high heat transfer rates [1]. Flame is a hot glowing mass of burning fuel and is a self-sustaining propagation of a localized combustion zone at supersonic velocities and high temperature gas jets.

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High pressure internal combustion oxygen and kerosine burners commercially known as jet piercers were first used for breaking rock in USA in 1950 [2]. Kerosine or diesel gas fired burners have dominated the burners for rock fracturing, cutting or drilling up till date around the world [3]. Kerosine or diesel gas is atomized into very fine particles by nozzle with filter in burner before it is burned [4]. Burner is a device used to combust fuel with oxidizer to convert chemical energy in fuel to thermal energy while nozzle is a narrow or tapering part at end of a tube used to direct or control flow of a fluid. The principle of flame jet burner is similar to oxygen and acetylene cutting torch used in metal works with pressure of about 15 bars and temperature of about 3200^{0}C [5], [6]. Flame jet burner is a device for burning mixed diesel gas and compressed air to generate flame at high temperature and high pressure.

Reference [1] reported tests performed with jet flames at Mines branch, Ottawa, Canada, that the most damage mechanism is due to heat, which is similar to oxy-acetylene heating damage. Reference [1] also stated that rate of energy input does not significantly change total energy required to produce a fixed amount of damage once the minimum rate has been exceeded which was obtained at instant of cracking at 400 ^{o}C. The flame jet as heat source induce thermal stresses that result in differential expansion of rock grains and fracture is then initiated which propagate until spalls are swept away by pressure, force and kinetic energy of compressed air. Combustion products are ejected through a nozzle, which increases the speed of ejection to 1,500–2,000 m/sec [7]. Thermodynamic parameters of gas flame jets decrease with increasing distance from the nozzle opening. At a distance on the order of 100–200 mm, jet-piercing drills using air as oxidizer have a stagnation temperature of 1,700°–2000°C and heat transfer of 3,500–4,500 watts (W) per (m^2·deg) from flame to the rock. By extension, flame jet drill using oxygen, has values of 2,400°–2700°K and 4,000–5,000 W/m^2·deg, respectively [7]. Furthermore, flame jet cutting rate is directly proportional to both pressure and fluids flow rate. When flame jet is directed at a point in kerf, the heat generated raises in-hole temperature up to 1800 ^{0}C, which creates thermal stresses that spall the rock [1].

Spallations are scale-like and relatively thin lamellae of materials that are violently dislodged from heated rock surface usually in conjunction with audible cracking noises as the flakes jump off the surface of parent rock mass [1]. Thermal spalling resistance is the ability of rock material to withstand sharp temperature changes without fracture, which is characterized by the number of heating up to 850^{o}C and cooling in air [8].

Thermal flame jet cutting is one of the first operations in granite block quarry that cuts all the vertical sides of a large rectangular block before breaking block away from the bedrock. The large rectangular block is then sliced and squared into smaller, regularly shaped block to be sawed and abrassively polished into products in processing factory. Thermal flame jet cutting of granite for dimension stone in Russian mines had an output of about 1- 2 m^3/hr, which is 1.5 to 2 times faster than conventional method of mechanical rock drilling and blasting [9]. Reference [10] reported thermal flame jet burner that was used to cut undersea double steel tube concrete piles and dam-screen to receive dam water in Japan.

Miya granite quarry is located in an outcrop at Kariya village, along Bauchi-Ningi road, Bauchi State, Nigeria and is owned by Mining and Granite Company, Limited, Bauchi (MGCL). Miya granite quarry produces dimension blocks for its own factory and supply to other firms for processing into slabs and tiles. Dimension stone can be defined as natural rock material that may be cut for the purpose of obtaining blocks, slabs or tiles that meet specifications as to size (width, length, and thickness) and shape. The slabs and tiles are commonly used for the cladding of buildings due to its colour, mechanical and architectural properties [11].

The objective of this work was to determine performance characteristics of a FA300A flame jet burner in cutting Miya granite for dimension stone.

II. MATERIALS AND METHOD

A. Material

Rock materials for dimension stone must conform to physical and chemical composition requirements prescribed by standards such as American standard for testing and materials [12]. The following tests were carried out by MGCL before establishment of the quarry at Miya [13]: absorption/specific gravity (ASTM C97), compressive strength (ASTM C170), modulus of rupture (ASTM C99), flexural strength (ASTM C880), abrasion resistance (ASTM C24) and chemical composition. Miya granite material in Miya quarry, Bauchi state, is a fine-medium grained rock made up of 27% quartz, 63% potassium feldspar, 4% plagioclase feldspar with 3% of micas.

B. Equipment

The air, fuel and flame jet burner units including air receivers, fuel storage tanks and air compressor were functional and manufactured by AtlasCopco [14]. The oxygen and acetylene cylinders, regulators and gauges were obtained from welding shop of the quarry.

a) *Air and fuel supply unit*

The fuel supply system consists of diesel tank, air motor, fuel pump, hoses, oil fog lubricator, pressure regulator, air dryer, filters and valves. The air is from XA350Dd AtlasCopco air compressor, which consists of rotary screw element of two helical rotor compressor, after cooler, oil separator, air receiver, condensate traps, air piping and flame jet burner air receiver. These result in separating mechanical impurities and increasing pressure and temperature of air and diesel gas for combustion. Air flow from the air compressor has 50 mm diameter pipeline and reduced at air receiver into 38 mm diameter pipe for the flame jet burner. The air side delivery pressure was at 0.6 kPa, which enhances mixing of fuel and air resulting in better air control. The compressed air with fuel, both flow into the combustion chamber. The air flows through an annulus surrounding the fuel tube resulting in minimum relative velocity between fuel and air streams. The mixtures mix slowly results in long luminous flame and long residence times within the fuel jet core and are favourable for production of soot that enhances uniform radiative heating over a large area [1]. Acetylene and oxygen were supplied from separate cylinders through pressure regulator, gauges into hoses, and enters knob control valve on the flame jet burner system. Table 1 shows the specification of the air and fuel supply units.

b) *Flame jet burner cutter*

The flame jet burner consists of control valves, flaming pipe that houses fuel and air passages as well as refractory pipe, which houses burner and heat resistant nozzle with filter and o-ring. Flaming pipe is part the operator (or driller) holds and manipulates to cut granite and also has connections and control valves.

Table 1: The Specifications of Air, Diesel Gas, Oxygen and Acetylene Gas Supply Units

S/N	Air Supply	Data	Diesel Gas Supply	Data	Oxygen and Acetylene Gas	Data
1	Air compressor	XA350Dd	Diesel tank	250 l	Oxygen cylinder (test)	22,753 kPa
2	Engine	F8L413F	Air filter	87 l/s	Oxygen hose	Green right
3	Air delivery	350 l/s	Pressure regulator	16 bars	Oxygen regulator	3 stage
4	Air pressure	6 bars	Oil fog lubricator	465 ml	Acetylene gas cylinder	Max103 kPa
5	Air receivers	500 l, 250 l	Air motor (vane)	2.88 kW	Acetylene gas hose	Red left
6	Line lubricator	7.6 l	Fuel pump	11 l/s	Flashback arrestor	Safety
7	Air hose	10 bars	Diesel hose	7 bars	Acetylene regulator	3 stage
8	Shut-off valve	38 mm	Knob control valve	13 mm	Knob control valves	13 mm

The control valves are one shut-off valve for compressed air and one knob valve for each of acetylene, oxygen and diesel gas. The diesel gas enters rear and flows through a central tube in flaming pipe resulting in atomization of diesel gas by air at nozzle tip placed at refractory pipe burner chamber where flame forms. A lighter and soaked diesel fuel rag serve as pilot igniter for the flame jet burner.

Specifications of the flame jet burner-cutter are as shown in Table 2.

C. Procedure

a) Preparation to start flame jet cutting

The overburden and boulders were removed from the granite outcrop by earth moving equipment and the surface was cleaned by use of compressed air to remove gravels, sand, other impurities or dry water. On the gentle slope of the outcrop, a vertical face was developed by drilling 30 mm diameter line holes, which were loaded with explosives and fired. A demarcation of rectangular block (bench) of 8 m long by 3 m depth by 3 m burden (depending on cracks, colouration, and other defects) was made on the outcrop. An imaginary kerf of 10 cm wide, from front to back at both ends of the bench was marked out with red paint, which was used as a directional guide during actual flame jet cutting as illustrated in Fig.1. On completion of flame jet cutting of both ends of the bench, the bench toe had line horizontal holes drilled while at bench burden had line vertical holes drilled, which were later loaded with explosives and fired to separate the rectangular block from parent rock. The symbols, θ, l and t represents outside diameter, length and breadth respectively.

Table 2: The Specifications of Flame Jet Burner for Cutting Granite for Dimension Stone.

S/N	Description	Specif.	S/N	Description	Specif.	S/N	Description	Specif.
1	Flaming rod (l_r)	2.0 m	5	Pipe burner θ_b	70 mm	9	Nozzle jet θ_j	2.5 mm
2	Flaming rod θ_r	60 mm	6	Pipe burner (t_b)	20 mm	10	Nozzle filter	Light oil
3	Flaming rod (t_r)	6 mm	7	Nozzle head (l_N)	65 mm	11	Nozzle extended	85 mm
4	Pipe burner (l_b)	0.6 m	8	Nozzle head θ_N	30 mm	12	Nozzle O-ring	

b) Ignition of flame jet burner

To start ignition of flame jet burner, compressed air, fuel, oxygen and acetylene valves were closed. Acetylene and oxygen gases were used for ignition of the flame jet burner. The acetylene valve of flame jet burner was gradually opened first and litted by placement of the burner in front of pilot light of burning diesel soaked rag placed about 1 m away from kerf line. The refractory pipe burner stabilized the flame within passageway. The oxygen valve was opened slowly to obtain flame visibility. The acetylene valve was opened further to adjust and stabilize the flame to neutral flame. Gradually, diesel and compressed air valves were opened while acetylene valve was slowly reduced. The overall adjustments of control valves were made to maintain neutral flame from carburizing flame of yellowish colour. When the cutting flame called rocket fire combustion was obtained, the acetylene valve was closed while diesel and air valves were slowly opened completely. About 3 minutes later, the oxygen valve was closed. Rocket fire combustion is neutral flame of several light blue inner cones in yellowish outer cone along the flame length. Occasionally, when the flame blows out during lighting or cutting, all the control valves are shut off immediately to restart the process.

c) Flame jet-cutting operation

The operator with an assistant who adjust the hoses took up the flame jet burner. The flame jet burner operates on pressure of about 6 bars and temperature of about 2600^{0}C in the combustion chamber and its nozzle outlet inclined at about 15^0 to axis of the burner. The flame jet burner was held pointing to the red painted marked kerf line in such away that the flame tongue does not spread out beyond sides of the kerf. The flame jet burner was used to heat the granite material to its spallation temperature and continuous heating made the top layer to flow out of the kerf as flakes. When mica or similar difficult to flake materials were met, mica in the kerf was first heated by the flame until it was cherry red and scrap broken-drilling rod was then used to dislodge the mica from the kerf. The burner was held at low angle initially and steepened later as cuttings go down to toe of the bench until desired kerf was formed. The flame jet burner was shut-off by closure of diesel gas valve until there was no flame and then compressed air valve was closed after about 10 minutes.

d) Performance tests

The procedure in testing of burner in reference [1] was modified for performance evaluation of thermal flame jet burner for cutting Miya granite blocks. For the testing to be done, the flame jet burner was operated under steady and full cutting operation for a period of one hour after which readings were taken during the next six hours of steady operation on each block to enable the performance parameters to be calculated [15]. Diesel fuel was measured initially at start of test, then 30 minutes after start and later every one-hour from previously calibrated storage tank by noting down diesel fuel levels difference during each of the kerf cutting operation. The surrounding air temperature was measured using k-type.

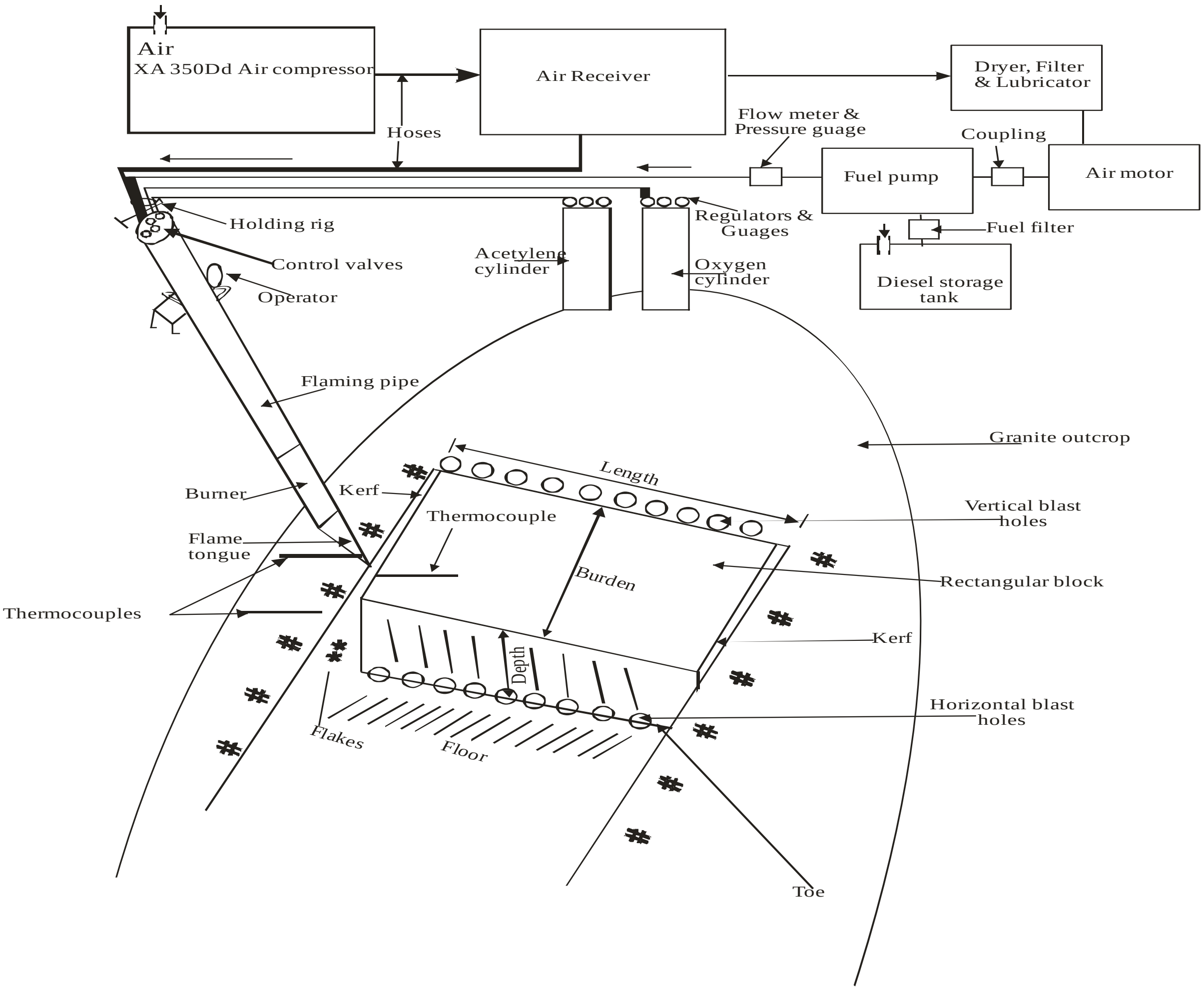

Fig.1: Complete Flame Jet Burner System used in Cutting Miya Granite for Dimension Stone

thermocouple while flame tongue and rock surface temperatures were measured by using pyro-thermocouple. The mass of flakes removed to create the kerf was calculated from measurement of length and depth of kerf cut. The flame shape, width and length were by visual observation. The constants are time, internal diameter of the burner and width of kerf of 10 cm for the performance test. Different kerfs for three rectangular blocks were cut each in 6 hrs and another 2 hrs of non recorded operations as shown in Table 3. The non-recorded operations includes preparatory works for actual flame jet burner in cutting granite, lifting and lowering the flame jet burner, cleaning bottom of cut, dislodging melting quartz and breakage of over-sized flakes as well as changing operator during a shift.

III. RESULTS AND DISCUSSION

A. Results

The performance characteristics of jet burner in cutting Miya granite for dimension stone are presented in Table3. The average depth of kerf cut was 3.20 m, for easy separation of the block from bench at toe. From experimental results on cutting of Miya granite by flame jet burner, the following performance parameters of the burner were determined using values in Tables 1-3:

Table 3: Diesel Gas Usage, Temperature Readings and Cutting Rates of Miya Granite

S/N	Time	Diesel (litres)	AmbientTemp.	Flame Tongue (°C)	Rock Surface Temp.(°C)	Block1 Kerf cut	Block2 Kerf cut	Block3 Kerf cut
1	0	0	35 °C	770	400	0 m^2	0 m^2	0 m^2
2	30 mins	30	37 °C	800	450	0.25 m^2	0.3 m^2	0.2 m^2
3	1 hr	59	43°C	930	500	1.05 m^2	1.10 m^2	0.85 m^2
4	2 hrs	113	45°C	940	620	2.05 m^2	2.20 m^2	1.85 m^2
5	3 hrs	166	47°C	950	630	3.13 m^2	3.38 m^2	2.70 m^2
6	4 hrs	218	48°C	955	650	4.16 m^2	4.56 m^2	3.70 m^2
7	5 hrs	269	48°C	960	652	5.06 m^2	5.74 m^2	4.70 m^2
8	6 hrs	319	50°C	962	653	6.26 m^2	6.82 m^2	5.90 m^2

a) *The internal cross sectional area of the flame jet burner*

The internal cross sectional area of the flame jet burner is given as:

$$A = \frac{\pi d^2}{4} \qquad (1)$$

where;

d is internal diameter of the flame jet burner from Table 2:

$$d = \theta_b - 2t_b$$

Substituting the values from Table 2

$$d = (70 - 2(20)) = 30\ mm.$$

Substituting value of d = 0.03 m into (1), internal area of the burner was found as:

$$A = \frac{\pi \times 0.033 \times 0.033}{4} = 0.00071\ m^2$$

ii *Heat input of the flame jet burner*

Refernce [16] gives heat input firing diesel gas in flame jet burner as:

$$Q \ = B_r LCV \qquad (2)$$

where;

B_r is fuel consumption rate = 53.17 l/hr (318 litres in 6 hrs from Table 3)

LCV is lower heating value of diesel fuel = 44,481 kJ/kg [17]

The mass flow rate of diesel fuel ($C_{10.8}H_{18.7}$) was found as:

$$B_r = \rho \times V \qquad (3)$$

where;

ρ is density of diesel fuel at 30^{o}C and 1 atm = 735 kg/m^3 [17]

V is volumetric flow rate of diesel fuel

= 53.17 l/hr x 0.001 m^3/l= 0.0532 m^3/hr

The values for V and ρ were substituted into (3) to yield the mass flow rate as follows:

$$B_r = 735 \times 0.0532 = 39.1 kg/hr = 0.01086\ kg/s$$

The heat input of the burner thus was found by substitution of B_r and LCV into (2) as follows:

$$Q \ = 0.01086 \times 44\ 481 = 483.1\ kW$$

iii *Heat release rate per unit internal cross sectional area of the burner*

The following relation in reference [16] gives heat release rate per unit area as:

$$q_a = \frac{Q}{A} \qquad (4)$$

Substituting for values of Q and A into (4) to obtain q_a as follows:

$$q_a = \frac{483.1}{0.000\ 71} = 680\ 433.5\ kW/m^2$$

Heat release rate per unit volume of flame jet burner is given as follows

$$q_v = \frac{Q}{A \times l_b} \qquad (5)$$

where;

l_b is length of pipe burner = 0.6 m (see Table 2).

Substituting the values Q, A and l_b to calculate q_v as follows:

$$q_v = \frac{483.1}{0.00071 \times 0.6} = 1\ 134\ 038\ kW/m^3$$

iv *Penetration rate*

Penetration rate is ability of rock to spall, expressed in a relation as follows [2]:

$$V_p = \frac{Q}{C_p \rho T_b} \qquad (6)$$

where;

C_p is specific heat capacity of granite rock = 0.882 kJ/kg°C [18]

ρ is rock density = 2650 kg/m^3

T_b is rock surface temperature at spalling averaged at 617.5°C

Substituting for the values for Q, ρ, T_b and C_p into (6) to yield V_p as follows:

$$V_p = \frac{609.4}{0.882 \times 2\,650 \times 617.5} = 0.42\ mm/s = 1.512\ m/hr$$

v Cutting speed

Cutting speed is a performance criterion that reflects length and depth of cut using flame jet burner. In other words is rate of dividing the block by the flame jet burner [19]:

$$S_c = \frac{K_A}{t_m} \qquad (7)$$

t_m is duration of cutting a kerf in hours or seconds
K_A is kerf area cut

$$K_A = b \times d \qquad (8)$$

where;

d is average depth of kerf cut = 3.20 m

b_b is average burden of kerf cut = 3 m

Substituting for the values of b_b, t_m and d into (7) to obtain S_c as follows:

$$S_c = \frac{3.20 \times 3}{6} = 1.60\ m^2/hr$$

vi Productivity of the flame jet burner

Productivity is intensity of cutting by burner as follows:

$$\Gamma = \frac{m}{A \times t} \qquad (9)$$

where;

A is area of burner (m^2)

m is of mass of rock excavated by flame jet burner (kg)

$$m = \rho \times V \qquad (10)$$

where;

ρ is rock density = 2650 kg/m^3

V is volume of rock excavated

$$V = d \times b_b \times W \qquad (11)$$

where;

W is average kerf width = 0.010 m

Substituting the values of d, b_b and W into (11) to obtain V as follows:

$$V = 3.20 \times 3 \times 0.01 = 0.096\ m^3$$

Substituting the values of m, V, ρ, A and t_m into (9) to yield productivity as follows:

$$\Gamma = \frac{2650 \times 0.096}{0.00071 \times 6 \times 3600} = 16.60\ kg/m^2 s$$

B. Discussion

The discussion of results was on solutions of empirical equations for performance evaluation of flame jet burner in cutting Miya granite for dimension stone. The performance criteria were on heat input, heat release rate, penetration rate, cutting speed and productivity of the flame jet burner in cutting Miya granite for dimension stone.

From Table 3 and subsequent solution for (2), heat input of the flame jet burner was 483.1 kW while similar flame jet burner employed by reference [19] was reported to have 371 kW. The difference might have arisen due to reliable fuel metering and fuel control system employed during their performance tests [19]. Further more, appropriate air flow rate was not measured to determine equivalence ratio of combustion process in this work. However, reference [19] utilised 60 l/s at 6 bars of compressed air to burn 30 kg/hr of diesel gas. Whereas 53.17 kg/hr of diesel gas utilised, which implies 77 l/s of compressed air was used to burn the 53.17 kg/hr of diesel. Air and fuel quantities are necessary in deployment and usage of air compressor for flame jet burner to cut granite.

The determined heat release rate per unit internal cross sectional area of the burner was 680,433.5 kW/m^2 in (4), which validates the desired heat concentration for spallation or flakes to occur in granite cutting for dimension stone [1]. The value of heat release rate per unit volume of burner of 1, 134, 038 kW/m^3 is high when compared to none-piercing heat transfer rate per unit volume of some combustor with heat release rate per unit volume of 2, 000 kW/m^3 [20].

Penetration rate determined in (6), for FA300A flame jet burner in cutting Miya granite for dimension stone was 0.44 mm/s (1.52 m/hr) whereas Canadian rock had penetration rate of 2.3 to 8.0 m/hr [2]. The experiments reported by reference [2], utilised flame jet burner with air pressure of 9 atm as against 6 atm in this work. In addition, the penetration rate reported by reference [2] was for confined hole of 25 mm-35 mm in diameter as against free surface on outcrop reported in this work. The differences are to be noted on the fact that penetration rate depends on several factors such as air pressure, distance between burner nozzle and rock surface as well as diameter of flame jet burner [3]. Furthermore, flakes from confined holes and high pressure are thinner than free surface and low air pressure flame jet burner [2], [10].

The cutting speed of flame jet burner of 1.65 m^2/hr was obtained in cutting Miya granite for dimension stone as calculated in (7). Reference [3] obtained cutting speed 2.0 m^2/hr for similar flame jet burner in their performance tests. The difference might have arisen due to variation in physical and chemical properties of minerals and rock even within one location.

The productivity of flame jet burner determined in (9) was 16.6 Kg/m^2.s in cutting Miya granite for dimension stone. The productivity of flame jet burner is an essential characteristic for comparing various flame jet burner or rocks, which reflects design, nature of heat transfer, thermal conditions of burner and rock or material subjected to spallation, intensity and flame temperature [8]. The surrounding high temperature, quartz and lobe melting, cupping, dust and noise generated by the cutting operation constitute its disadvantages. Flame jet burner application in cutting Miya granite for dimension stone has high productivity and useful in rock with high quartz content. Flame jet burner cutting was effective since much smaller quantities of rock were displaced, handled and processed into flaky aggregates while major recovery are the commercial blocks.

IV. CONCLUSIONS

The flame jet burner in cutting Miya granite for dimension stone was investigated. The performance characteristics were measured for a range of time and experimental conditions in Miya dimension stone quarry. The results will assist engineers on continued need for improve efficiency and productivity when flame jet burners are employed in cutting granite blocks against competition from diamond wire cutting machines

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