韓國海洋工學會誌 第13卷 第1號, pp.70~78, 1999. 2

◉ 論　文

A Study on the Deep Hole Drilling for Refractory Metals
(STS type BTA drilling for SKD11 high alloy tool steel)

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(99년 1월 7일 접수)

난삭재의 심공가공에 관한 연구
(SKD11고합금공구강에 대한 STS타입 BTA드릴 가공)

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Key Words : BTA(Boring and Trepanning Association) Drill, SKD11 Tool Steel, Surface Roughness, Roundness, Cylindricity, Straightness, Hole Expansion, STS (Single Tube System)

Abstract

오늘날 기계공업 현장에서 심공드릴가공은 광범위한 응용과 양호한 생산성으로 인하여 그 요구가 증가 되고 있다. 그러므로, 본 연구는 난삭재인 SKD11고합금공구강을 여러가지 절삭 조건하에서 BTA드릴가공 하여 얻은 실험결과(표면조도, 진직도, 진원도, 원통도, 구멍확대량, 등)를 다루었으며 이들의 이론적 배경과 실험을 비교 분석하였다. 프레스금형 부품과 기계부품으로 사용되고 있는 SKD11고합금공구강은 기계가공이 힘든 난삭재료로서 그 어려움이 크므로 본 연구는 생산현장에 보다 나은 심공드릴가공결과와 관련 지식을 제공 할수 있다고 사료된다.

1. Introduction

The deep hole drilling is defined as that the drilling length to diameter ratio is over 5 and can be classified largely as BTA (Boring and Trepanning Association) drilling and gun drilling.

In tip configuration, fluid induction, chip removal and BTA drilling differs from the conventional gundrill. However supporting bearing

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arrangement is similar to the conventional gundrill and the basic guidance is identical. The tool cuts in a true circular pattern and the tip follows to the direction of its own axis and is mounted to a tubular steel shank. The tooling is designed for deep hole drilling machine or specially equipped with horizontal lathes. Both of them must include a large volume and high pressure fluid system. Such a system can result in high production rates, accurate depth or shallow holes with good surface finish. The BTA drilling was studied by Beisner, Pearson, Griffiths, Evans, Pfleghr, Rao, Osman. Sakuma, Taguchi, Osman and et.al about the optimum cutting edge design of BTA drill which can give minimum cutting force.[1) 2)]

Also Sakuma and Taguchi studied about the profile of deep hole and its generating mechanism,

but in those study, the lobe characteristics, the refractory metals deep drilling phenomenas, were not investigated for complete theoretical or experimental results. Accordingly, this study has tried to investigate more complete characteristics of the refractory metals and the accuracy of refractory metal's BTA drilled workpiece by performing CNC STS type BTA drilling with tool rotating head.[1) 3) 5)]

2. BTA drill

Fig. 1 shows the direction that the cutting force acts on the cutting tool edges during BAT drilling.

The cutting force Fc is as follows.[3)]

$$F_c = K_s\ f\ D/2 \tag{1}$$

where, K_s : Specific cutting force ratio

F_c : Cutting force

f : Feed rate

D : Drilling diameter

In this case, if the cutting force is $F = K_s\ f\ r$ and acting radius is r, cutting torque M_c is as follows.

$$Mc = \int_0^{\frac{D}{2}} Fdr = \frac{Ks}{8} f D^2 \tag{2}$$

The friction force is F_s and F_r of the 1st guide pad and the 2nd guide pad. The creating results of these factors, friction torque M_f between hole surface and tool edges is shown by next equation.

$$M_f = \mu(F_s + F_r)\frac{D}{2} \tag{3}$$

The value of F_r as a statistics method becomes $\frac{F_s}{4}$, F_s value which is same with F_c approximately, therefore, the value of friction torque M_f is as the following equation.[2)]

$$\begin{aligned} Mf &= \mu \frac{5}{4} F_s \frac{D}{2} \\ &= \frac{5}{8} \mu F_s D \\ &= \frac{5}{16} \mu K_s f D^2 \\ &= 2.5 \mu Mc \end{aligned} \tag{4}$$

The burnishing torque M_b generated by the guide pad during drilling should be considered. The whole drilling torque, M is the sum of M_c, M_f and M_b,

$$\begin{aligned} M &= M_c + M_f + M_b \\ &= (1 + 2.5\mu + C_b) K_s\ f\ \frac{D^2}{8} \end{aligned} \tag{5}$$

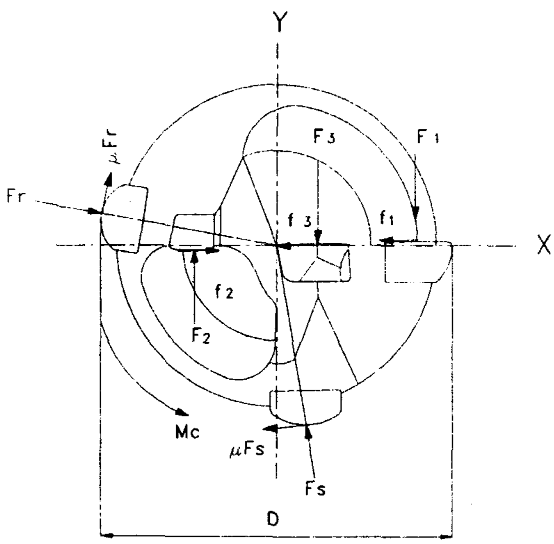
when C_b = Mb/Mc.

The thrust T is the sum of T_c (BTA drill tube's longitudinal direction component of the cutting force on the cutting edge), T_b (burnishing thrust) and T_0 (coolant pressure).

Upper factors are in the next formula formed.

$$T = T_c + T_b + T_0$$
$$= \frac{2}{3}F_c + (0{\sim}0.1)F_c + \frac{\pi}{4}D^2P_c$$
$$= (0.33{\sim}0.35)K_s\, f\, D + (0.25{\sim}0.4)P_s\, D^2 \quad (6)$$

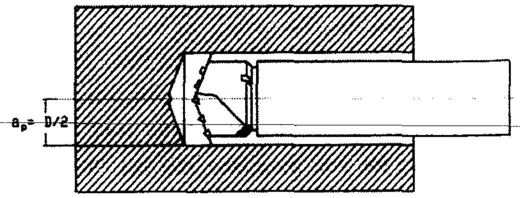
Where, P_c is the pressure at the oil gap and equal to $(0.25{\sim}0.4)\frac{\pi}{4}P_s$, P_s which is the oil supply pressure.



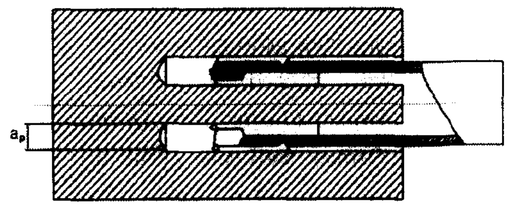
$F_c = F_1 + F_2 + F_3$

Fig. 1 Cutting force direction BTA drill head[3)]

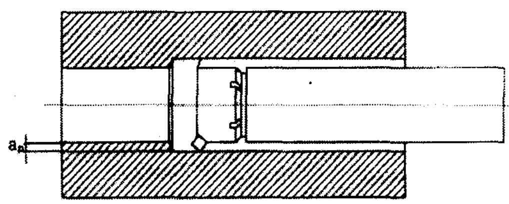
Fig. 2 shows the three kinds of BTA drilling method. In this figure, fig.(a) described the solid type BTA drill head working situation, fig.(b) shows the trepanning drill head working of the core remaining from workpiece and fig.(c) shows the counter boring head working after solid type predrilling.



(a) Solid drilling



(b) Trepanning



(c) Counterboring

a_p : Cutting depth

Fig. 2 BTA drilling description[4)].

3. Experimental Method

3.1 Experimental Apparatus

Table 1 is the list of experimental machine and instruments. In this experiment, deep hole drilling machine used was the type of workpiece fixed with angle type device on the table and tool rotating type CNC deep hole drilling machine, and the coolant was machining oil

(S-CUT-7E) under 2.5MPa fluid pressure conditions.

3.2 Workpiece and Drill

In this experiment, the workpieces and tools used appeared in Table 2 and chemical compositions, and mechanical properties in Table 3. For the removal of internal stress, heat-treatment was taken and the BTA drilling was performed suitable to the experimental conditions.

Table 1 List of experimental apparatus

No.	Name	Model	Maker
1	Deep hole drilling machine	BTA 1500CNC	Shin Il M/C Co.
2	Surface roughness tester	ISO/6	Talyor Hobson
3	Roundness tester	RTH TR150	〃
4	BTA drill	P30 Ø19.25	Korea Tungsten Co.
5	Straightness tester	Unfiltrde	Taylor Hobson
6	Hole test	0.005 Ø16~Ø20	Mitutoyo
7	Lathe	1800	Hwa cheon machinery Co. Ltd.

Table 2 List of drill and workpiece

Drill diameter	Drill material	Workpiece size	Workpiece material
Ø19.25	P30	Ø40×200 Ø35×150	SKD11

Table 3 Chemical compositions & mechanical properties of workpiece (SKD11, round bar)

Chemical compositions(Wt. %)										Mechanical properties HB
C	Mo	Si	Mn	P	Ni	Cr	Mo	V	Cu	223 to 255
1.50	0.80	0.40	0.60	0.030	0.50	12.00	1.00	0.15	0.25	

3.3 Experimental Method

In BTA drilling experiments, an angular type fixture was installed on the CNC deep hole machine table, and then the work piece was loaded on the V type clamping block within the tool alignment ±0.025mm adjusted.

At the same time, the BTA drill head and drill tube fixed were assembled with the collet chuck. Finally, those penetrated through guide bush, and then performed the deep hole machining according to macroprogram operation. In additional experiments, deep hole profile measurement was performed with profile measuring instruments and also roughness tester, etc. Fig. 3 shows the exprimental deep hole drilled workpiece shape.

Table 4 BTA drilling condition

No	Cutting Speed (m/min)	Revolution (rpm)	Feed (mm/rev)	Feed (mm/min)
1	55	909.99	0.14	127.39
2		〃	0.17	154.69
3		〃	0.20	181.99
4	60	992.72	0.14	138.98
5		〃	0.17	168.76
6		〃	0.20	198.54
7	70	1158.17	0.14	162.14
8		〃	0.17	196.88
9		〃	0.20	231.63
10	75	1240.90	0.14	173.72
11		〃	0.17	210.95
12		〃	0.20	248.18
13	80	1323.62	0.14	185.30
14		〃	0.17	225.01
15		〃	0.20	264.72
16	90	1489.08	0.14	208.47
17		〃	0.17	253.14
18		〃	0.20	297.81
19	100	1654.53	0.14	231.63
20		〃	0.17	281.27
21		〃	0.20	330.90

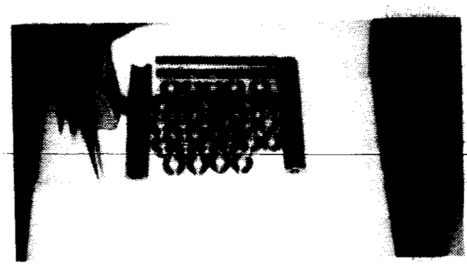


Fig. 3 Experimental deep hole drilled workpiece

4. Experimental Results and Considerations

4.1 Surface Roughness

Fig. 4 described the surface roughness of BTA drilled workpiece. As results of surface roughness(Ra) versus cutting speed, feed rate, the whole trend is under the 0.59μm Ra value.

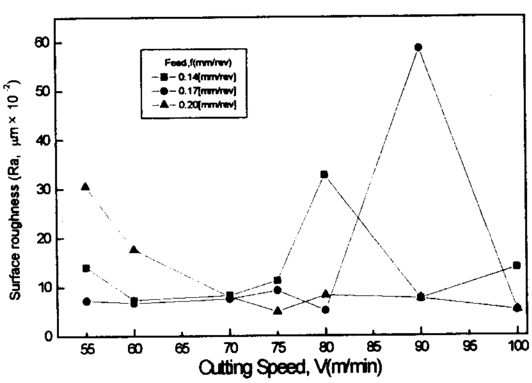


Fig. 4 Surface roughness Vs. Cutting speed

This result is an appropriate value on the machining efficiency. We can consider that the result is displaying of burnishing efficiently by guide pad behaviour, and this reveals that the reaming or post machining is unnecessary. On the side of the cutting speed, under the cutting condition of 60, 70, 75, 100m/min, the surface roughness should be below the 0.20μm Ra value. Thus, we can consider the finest productivity, the result is suitable, and also this result comes from plastic deformation of the BTA drill's guidepad behaviour. At this time, we can suppose that the plastic deformation energy is minimizing value.

4.2 Straightness

The straightness is related to accuracy with cylindricity in Fig. 5. The cutting speed V=75m/min, 80m/min and feed rate f=0.20m/rev. are the least numerical value of straightness. It is possible that we can consider that the cutting speeds V=55, 60, 70, 75, 80 m/min, feed rate f=0.17mm/rev. are very fine to select in field.

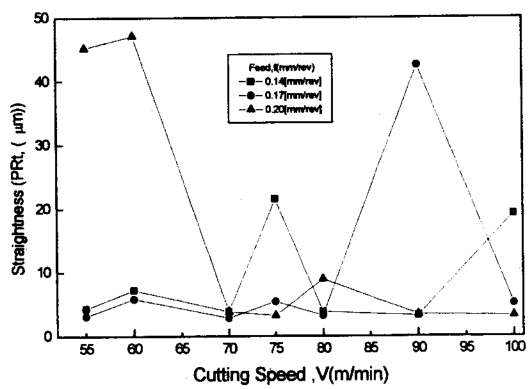


Fig. 5 Straightness (peak to valley) Vs. Cutting speed

4.3 Cylindricity

Fig. 6 shows the cylindricity of BTA drilled hole. The cylindricity results which appeared most suitable in value at the cutting speed V=70m/min, the feed rate f= 0.14, 0.17, 0.20m/rev. are very fine drilling conditions, but the selection of suitable cutting condition is feed rate f=0.14mm/rev. cutting speed V=55~90m/min, as the cause of the 5μm value of cylindricity. In the view of whole accuracy of cylindrical phenomena is considered very adaptive that the amount of numerical value is less than 50μm.

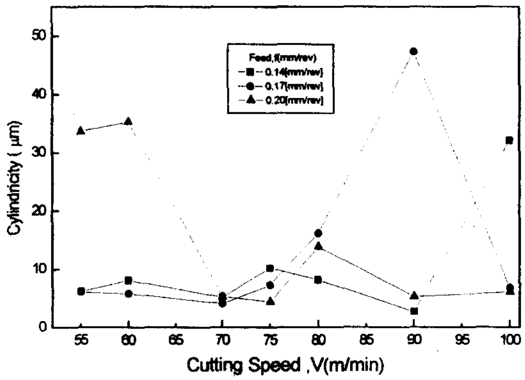


FIg. 6 Cylindricity Vs. Cutting speed

4. 4 Roundness

Fig. 7 is the experimental result of roundness. In this figure, the most suitable cutting condition is the cutting speed V=90 m/min, and feed rate f=0.14 mm/rev. This trend is increasing as every speed of tool revolution by the reason of roundness increasing the principle of metal cutting defined. But in the conditions of the feed rate f=0.17mm/rev, cutting speed V=55,60,70 mm/min, the roundness is between the 1.2μm and 2.1μm. Hence, the second time machining such as grinding or mirror machining is unnecessary. This results are proved that the high turning velocity, namely high RPM increases the roundness of drilling hole profile.

4. 5 Profile of Lobe

We can find 2 to 5 lobes mostly in this experimental results. In the case of the upper 4 lobes it can be known that fine profile is mostly.

In the Fig. 8(a)(b)(c)(d)(e)(f), 2 to 8 lobes were found.

The lobe creating is obtained from following formula.[1) 4) 5) 6)]

$$|\vec{R}| = \sqrt{X^2 + Y^2}$$

$$= \frac{1}{2}\sqrt{[D_a^2 + D_t^2 + 2D_a D_t \cos((nz-1)\omega_t t + (\Phi_0 - \theta_0))]} \quad (7)$$

The above formula means that the $|nz-1|$ lobes are formed. In this case, n= integer, ωa= tool axis angular velocity, ωt=tool angular velocity, Da=revolution diameter, Dt=tool diameter, $|\vec{R}|$ = vector locus by work piece lobe radius, ϕ_0, θ_0= initial phase, Z= number of cutting edges. By the above formula, we could calculate as appeared in Fig. 9 graphics. Hence, we can find that the lobe creating is obtained from frequency behaviour too (as shown at the presentation in 1997 ISOPE Conference.[5)]

In the experiment, we found above 5 lobes of BTA drilled workpiece. This result means that the BTA drilling condition, tool alignment, coolant, etc. were within the best environment.

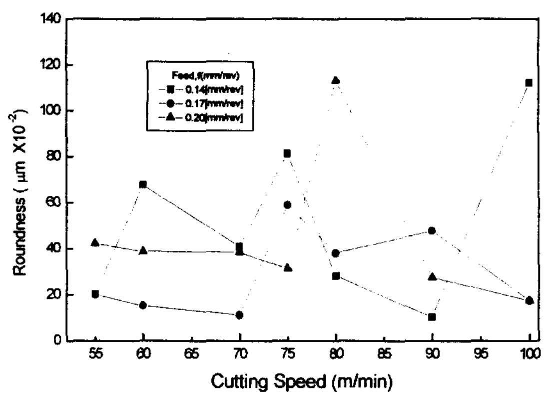


Fig. 7 Roundness Vs. Cutting speed

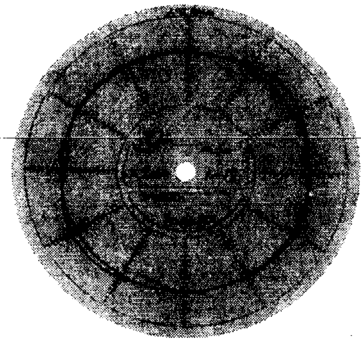


Fig. 8 (a) Experimental locus of 2 lobes profile for BTA drilled hole
(Ø19.25, V=75 m/min, f=0.20mm/rev)

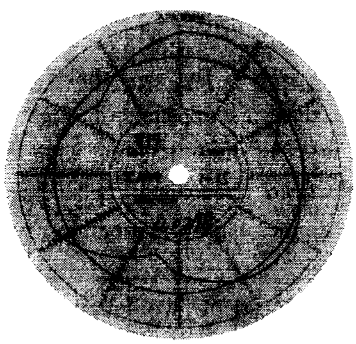


Fig. 8(b) Experimental locus of 3 lobes profile for BTA drilled hole
(Ø19.25, V=100m/min, f=0.14mm/rev)

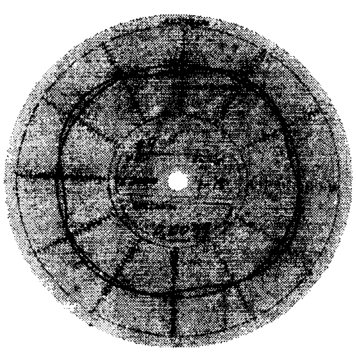


Fig. 8(c) Experimental locus of 4 lobes profile for BTA drilled hole
(Ø19.25, V=70m/min, f=0.20mm/rev)

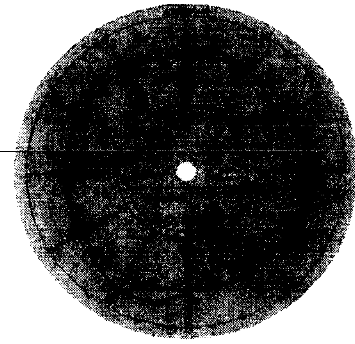


Fig. 8(d) Experimental locus of 5 lobes profile for BTA drilled hole
(Ø19.25, V=75m/min, f=0.20mm/rev)

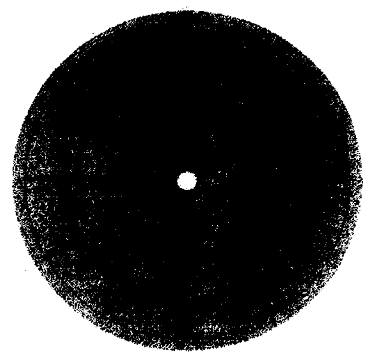


Fig. 8(e) Experimental locus of above 6 lobes profile for BTA drilled hole
(Ø19.25, V=90m/min, f=0.20mm/rev)

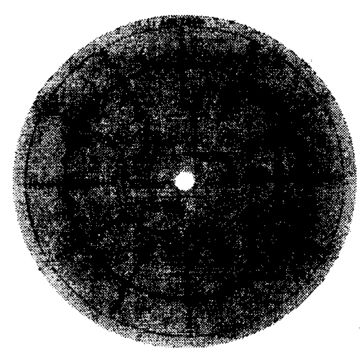


Fig. 8(f) Experimental locus of above 8 lobes profile for BTA drilled hole
(Ø19.25, V=70m/min, f=0.17mm/rev)

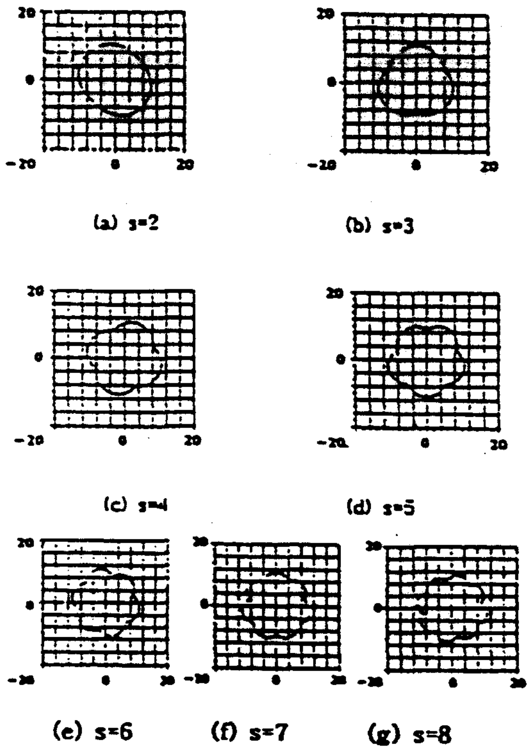


Fig. 9 Theoretical locus of lobe[6]

4.6 Hole expansion

Fig. 10 shows the BTA drilled workpiece hole expansion phenomena.In this figure, the largest expansion is 10 μm and the least amount of hole expansion is 1 μm.Therfore, it is provided that the cutting condition was very fine adaptabe, tool alignment was very accurate within ±0.025mm, also, BTA drill tube rest was the finest location and bearing condition was best one too.

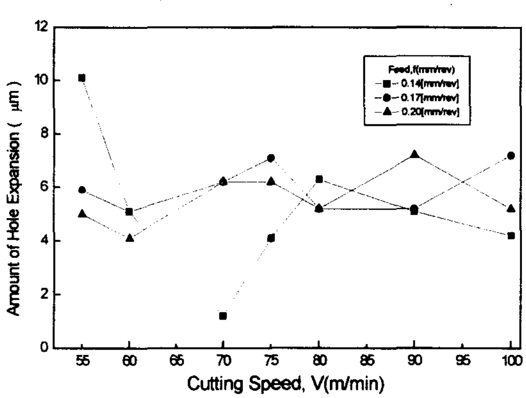


Fig. 10 Amount of hole expansion Vs. Cutting speed (Ø19.25×180)

5. Conclusion

The conclusion of ϕ 19.25 BTA deep hole drilling on the SKD11 high alloy tool steel, CNC deep hole drilling was as follows

1) The Machining surface roughness numerical value is very small amount from fine BTA drill cutting and guide pad activities.
2) After BTA deep hole drilling, the cylindricity of the workpiece was fine under the best tool aligment, coolant, etc. It is proved that the fine cylindricity comes from tooling enviroment.
3) As the same situation, straightness cylindricity, roundness and hole expansion were fine in the case of V=50~100m/min cutting speed, f=0.14~0.20mm/rev feed rate approximately in this study.
4) The lobe profile was similar to the calculated result and appealed above 5 lobes of BTA drilled hole mostly.

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