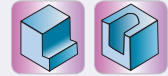
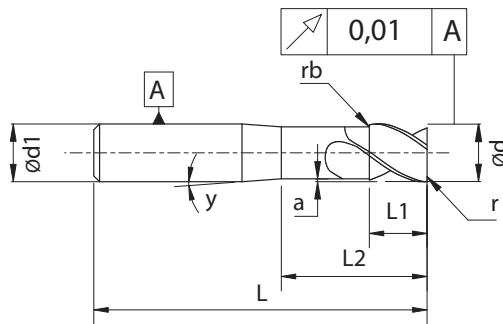


# 4 Flute

## Centre cutting high performance 4 flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

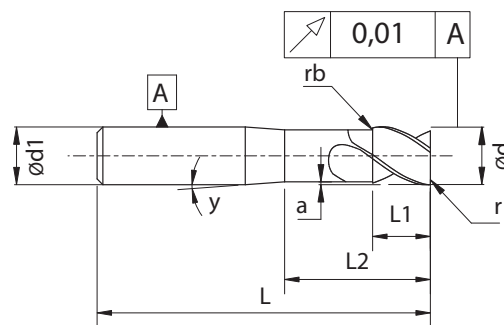
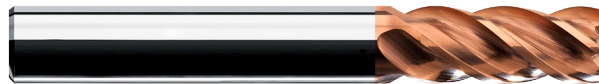
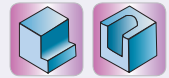
Unit : mm

Ød (mm)	r (mm)	Ød1 (mm)	L (mm)	L1 (mm)	L2 (mm)	a (mm)	z	γ 0.5°	EDP No
<b>Short</b>									
3	0.2	6	39	5	7	0.1	4	15	FBK0505836
4	0.2	6	51	6	9	0.1	4	15	FBK0505837
5	0.2	6	51	7	11	0.2	4	15	FBK0505838
6	0.3	6	64	8	13	0.2	4	-	FBK0505070
6	0.5	6	64	8	13	0.2	4	-	FBK0505071
6	1	6	64	8	13	0.2	4	-	FBK0505072
8	0.3	8	64	11	18	0.3	4	-	FBK0505839
8	0.5	8	64	11	18	0.3	4	-	FBK0505840
8	1	8	64	11	18	0.3	4	-	FBK0505073
10	0.3	10	70	13	22	0.3	4	-	FBK0505841
10	0.5	10	70	13	22	0.3	4	-	FBK0505842
10	1	10	70	13	22	0.3	4	-	FBK0505075
12	0.3	12	78	15	25	0.3	4	-	FBK0505843
12	0.5	12	78	15	25	0.3	4	-	FBK0505076
12	1	12	78	15	25	0.3	4	-	FBK0505844
14	1	14	89	17	30	0.3	4	-	FBK0505845
16	0.5	16	89	19	35	0.3	4	-	FBK0505846
16	1	16	89	19	35	0.3	4	-	FBK0505847
20	0.5	20	102	23	42	0.4	4	-	FBK0505848
20	1	20	102	23	42	0.4	4	-	FBK0505849
25	0.5	25	120	28	45	0.4	4	-	FBK0505850
25	1	25	120	28	45	0.4	4	-	FBK0505851

Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074

# 4 Flute

## Centre cutting high performance 4 flute end mill for exotic materials



P1-P6

K1-K2

M1-M3

S1-S4

H1

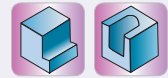
Unit : mm

Ød	r	Ød1	L	L1	L2	a	z	γ	EDP No
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		0.5°	
<b>Standard</b>									
3	0.2	6	39	7	-	-	4	15	FBK0505852
4	0.2	6	51	9	-	-	4	15	FBK0505853
5	0.2	6	51	11	-	-	4	15	FBK0505854
6	0.3	6	64	13	-	-	4	-	FBK0505104
6	0.5	6	64	13	-	-	4	-	FBK0505105
6	1	6	64	13	-	-	4	-	FBK0505106
8	0.3	8	64	18	-	-	4	-	FBK0505855
8	0.5	8	64	18	-	-	4	-	FBK0505856
8	1	8	64	18	-	-	4	-	FBK0505108
10	0.3	10	70	22	-	-	4	-	FBK0505857
10	0.5	10	70	22	-	-	4	-	FBK0505858
10	1	10	70	22	-	-	4	-	FBK0505110
12	0.3	12	78	25	-	-	4	-	FBK0505859
12	0.5	12	78	25	-	-	4	-	FBK0505111
12	1	12	78	25	-	-	4	-	FBK0505860
14	1	14	89	30	-	-	4	-	FBK0505861
16	0.5	16	89	35	-	-	4	-	FBK0505862
16	1	16	89	35	-	-	4	-	FBK0505863
20	0.5	20	102	42	-	-	4	-	FBK0505864
20	1	20	102	42	-	-	4	-	FBK0505865
25	0.5	25	120	45	-	-	4	-	FBK0505866
25	1	25	120	45	-	-	4	-	FBK0505867

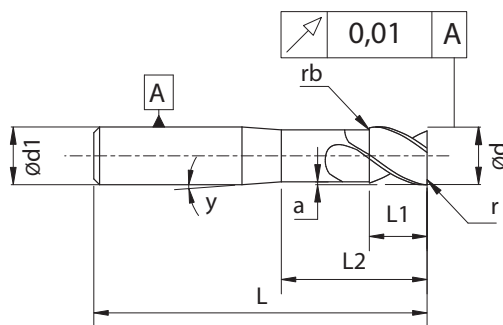
Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074

# 4 Flute

## Centre cutting high performance 4 flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød (mm)	r (mm)	Ød1 (mm)	L (mm)	L1 (mm)	L2 (mm)	a (mm)	z	γ 0.5°	EDP No
<b>With neck relief</b>									
3	0.2	6	39	7	9	0.1	4	15	FBK0505868
4	0.2	6	51	9	12	0.1	4	15	FBK0505869
5	0.2	6	51	11	15	0.2	4	15	FBK0505870
6	0.3	6	64	13	18	0.2	4	-	FBK0505871
6	0.5	6	64	13	18	0.2	4	-	FBK0505872
6	1	6	64	13	18	0.2	4	-	FBK0505873
8	0.3	8	64	18	24	0.3	4	-	FBK0505874
8	0.5	8	64	18	24	0.3	4	-	FBK0505875
8	1	8	64	18	24	0.3	4	-	FBK0505876
10	0.3	10	70	22	30	0.3	4	-	FBK0505877
10	0.5	10	70	22	30	0.3	4	-	FBK0505878
10	1	10	70	22	30	0.3	4	-	FBK0505879
12	0.3	12	83	25	36	0.3	4	-	FBK0505880
12	0.5	12	83	25	36	0.3	4	-	FBK0505881
12	1	12	83	25	36	0.3	4	-	FBK0505882
12	0.3	12	102	25	36	0.3	4	-	FBK0505883
12	0.5	12	102	25	36	0.3	4	-	FBK0505884
12	1	12	102	25	36	0.3	4	-	FBK0505885
14	1	14	102	30	42	0.3	4	-	FBK0505886
16	0.5	16	102	35	48	0.3	4	-	FBK0505887
16	1	16	102	35	48	0.3	4	-	FBK0505888
20	0.5	20	125	42	60	0.4	4	-	FBK0505889
20	1	20	125	42	60	0.4	4	-	FBK0505890
25	0.5	25	131	45	75	0.4	4	-	FBK0505891
25	1	25	131	45	75	0.4	4	-	FBK0505892

Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074



Solid Carbide End Mills

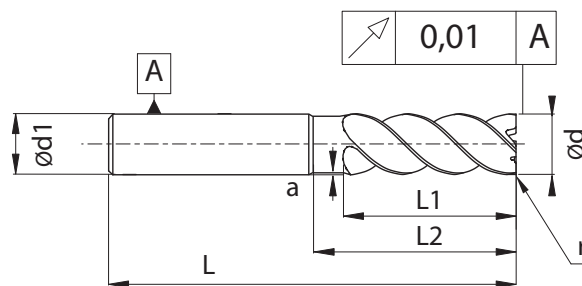
Proton HD Series

5 Flute

Centre cutting high performance  
5 flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød	r	Ød1	L	L1	L2	a	z	γ	EDP No
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		(°)	
<b>Short</b>									
3	0.2	6	39	5	7	0.1	4	15	FBK0505893
4	0.2	6	51	6	9	0.1	4	15	FBK0505894
5	0.2	6	51	7	11	0.2	4	15	FBK0505895
6	0.3	6	64	8	13	0.2	4	-	FBK0505896
6	0.5	6	64	8	13	0.2	4	-	FBK0505897
6	1	6	64	8	13	0.2	4	-	FBK0505898
8	0.3	8	64	11	18	0.3	4	-	FBK0505899
8	0.5	8	64	11	18	0.3	4	-	FBK0505900
8	1	8	64	11	18	0.3	4	-	FBK0505901
10	0.3	10	70	13	22	0.3	4	-	FBK0505902
10	0.5	10	70	13	22	0.3	4	-	FBK0505903
10	1	10	70	13	22	0.3	4	-	FBK0505904
12	0.3	12	78	15	25	0.3	4	-	FBK0505905
12	0.5	12	78	15	25	0.3	4	-	FBK0505906
12	1	12	78	15	25	0.3	4	-	FBK0505907
14	1	14	89	17	30	0.3	4	-	FBK0505908
16	0.5	16	89	19	35	0.3	5	-	FBK0505909
16	1	16	89	19	35	0.3	5	-	FBK0505910
20	0.5	20	102	23	42	0.4	5	-	FBK0505911
20	1	20	102	23	42	0.4	5	-	FBK0505912
25	0.5	25	120	28	45	0.4	5	-	FBK0505913
25	1	25	120	28	45	0.4	5	-	FBK0505914

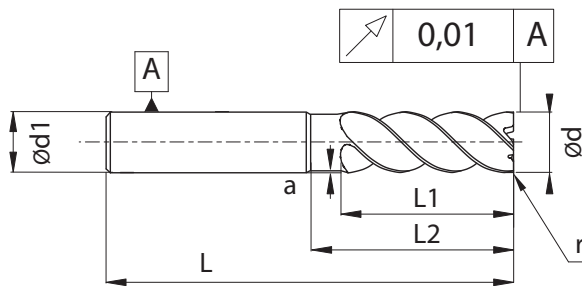
Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074

5 Flute

Centre cutting high performance  
5 flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød	r	Ød1	L	L1	L2	a	z	γ	EDP No
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		(°)	
<b>Standard</b>									
3	0.2	6	39	7	-	-	5	15	FBK0505915
4	0.2	6	51	9	-	-	5	15	FBK0505916
5	0.2	6	51	11	-	-	5	15	FBK0505917
6	0.3	6	64	13	-	-	5	-	FBK0505918
6	0.5	6	64	13	-	-	5	-	FBK0505919
6	1	6	64	13	-	-	5	-	FBK0505920
8	0.3	8	64	18	-	-	5	-	FBK0505921
8	0.5	8	64	18	-	-	5	-	FBK0505922
8	1	8	64	18	-	-	5	-	FBK0505923
10	0.3	10	70	22	-	-	5	-	FBK0505924
10	0.5	10	70	22	-	-	5	-	FBK0505925
10	1	10	70	22	-	-	5	-	FBK0505926
12	0.3	12	78	25	-	-	5	-	FBK0505927
12	0.5	12	78	25	-	-	5	-	FBK0505928
12	1	12	78	25	-	-	5	-	FBK0505929
14	1	14	89	30	-	-	5	-	FBK0505930
16	0.5	16	89	35	-	-	5	-	FBK0505931
16	1	16	89	35	-	-	5	-	FBK0505932
20	0.5	20	102	42	-	-	5	-	FBK0505933
20	1	20	102	42	-	-	5	-	FBK0505934
25	0.5	25	120	45	-	-	5	-	FBK0505935
25	1	25	120	45	-	-	5	-	FBK0505936

Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074



Solid Carbide End Mills

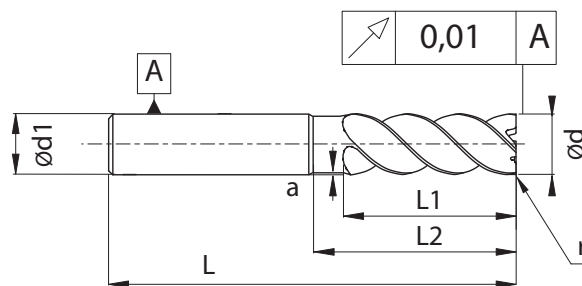
Proton HD Series

5 Flute

Centre cutting high performance  
5 flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød	r	Ød1	L	L1	L2	a	z	γ	EDP No
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)		(°)	
<b>With neck relief</b>									
3	0.2	6	39	8	9	0.1	5	15	FBK0505937
4	0.2	6	51	10	12	0.1	5	15	FBK0505938
5	0.2	6	51	12	15	0.2	5	15	FBK0505939
6	0.3	6	64	14	18	0.2	5	-	FBK0505940
6	0.5	6	64	14	18	0.2	5	-	FBK0505941
6	1	6	64	14	18	0.2	5	-	FBK0505942
8	0.3	8	64	18	24	0.3	5	-	FBK0505943
8	0.5	8	64	18	24	0.3	5	-	FBK0505944
8	1	8	64	18	24	0.3	5	-	FBK0505945
10	0.3	10	70	22	30	0.3	5	-	FBK0505946
10	0.5	10	70	22	30	0.3	5	-	FBK0505947
10	1	10	70	22	30	0.3	5	-	FBK0505948
12	0.3	12	102	26	36	0.3	5	-	FBK0505949
12	0.5	12	102	26	36	0.3	5	-	FBK0505950
12	1	12	102	26	36	0.3	5	-	FBK0505951
14	1	14	102	30	42	0.3	5	-	FBK0505952
16	0.5	16	102	35	48	0.3	5	-	FBK0505953
16	1	16	102	35	48	0.3	5	-	FBK0505954
20	0.5	20	125	42	60	0.4	5	-	FBK0505955
20	1	20	125	42	60	0.4	5	-	FBK0505956
25	0.5	25	131	45	75	0.4	5	-	FBK0505957
25	1	25	131	45	75	0.4	5	-	FBK0505958

Shank diameters starting from Ø 6 mm also available in weldon  
Application data on page no 2.074



**Cutting conditions**

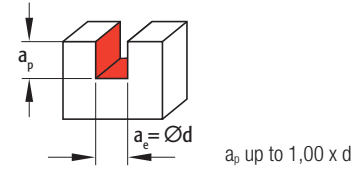
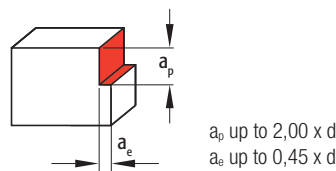
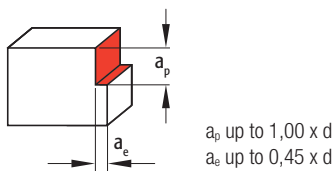
- Center cutting high performance 4 flute end mills for roughing/semi finishing of exotic materials
- Center cutting high performance 5 flute end mills for roughing/semi finishing of exotic materials

Material group	TSR	Hardness	Cutting speed	Coolant
	(N/mm <sup>2</sup> )	HRc	Vc m/min	
P3	< 750	< 35 HRc	140 - 220	emulsion
P4	< 1000	< 35-48 HRc	100 - 180	emulsion
P4	< 1400	< 35 HRc	70 - 160	emulsion
H1		42-50 HRc	80 - 140	emulsion
M1	< 600		80 - 130	emulsion
M2	600-800	< 25 HRc	60 - 100	emulsion
M3	< 800	< 30 HRc	60 - 100	emulsion
K1	< 800		100 - 160	emulsion
S1	500-1200	25-48 HRc	40 - 60	emulsion
S2	1000-1500	25-48 HRc	45 - 70	emulsion
S3	600-1700	<48 HRc	30 - 50	emulsion
S4	900-1600	33-48 HRc	60 - 90	emulsion



**Advantages**

- High performance
- Productivity
- Tool life
- Surface finish



**Shoulder milling**

**Shoulder milling**

**Slot milling**

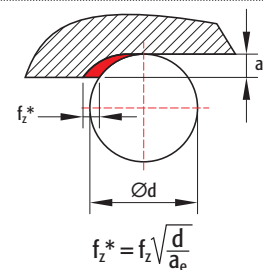
(1xD depth of cut)			
Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
3	< 3.0	< 1.4	0.010 - 0.020
4	< 4.0	< 1.8	0.015 - 0.030
5	< 5.0	< 2.3	0.020 - 0.040
6	< 6.0	< 2.7	0.025 - 0.050
8	< 8.0	< 3.6	0.030 - 0.060
10	< 10.0	< 4.5	0.040 - 0.070
12	< 12.0	< 5.4	0.050 - 0.080
14	< 14.0	< 6.3	0.055 - 0.090
16	< 16.0	< 7.2	0.060 - 0.100
20	< 20.0	< 9.0	0.080 - 0.120
25	< 25.0	< 11.3	0.100 - 0.150

(2xD depth of cut)			
Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
3	< 6.0	< 0.75	0.010 - 0.030
4	< 8.0	< 1.00	0.020 - 0.040
5	< 10.0	< 1.25	0.025 - 0.055
6	< 12.0	< 1.50	0.035 - 0.065
8	< 16.0	< 2.00	0.045 - 0.075
10	< 20.0	< 2.50	0.055 - 0.085
12	< 24.0	< 3.00	0.070 - 0.100
14	< 28.0	< 3.50	0.080 - 0.120
16	< 32.0	< 4.00	0.090 - 0.130
20	< 40.0	< 5.00	0.110 - 0.150
25	< 50.0	< 6.25	0.135 - 0.185

Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
3	< 3.0	3	0.005 - 0.015
4	< 4.0	4	0.008 - 0.025
5	< 5.0	5	0.010 - 0.030
6	< 6.0	6	0.015 - 0.035
8	< 8.0	8	0.025 - 0.045
10	< 10.0	10	0.030 - 0.050
12	< 12.0	12	0.035 - 0.060
14	< 14.0	14	0.040 - 0.070
16	< 16.0	16	0.050 - 0.080
20	< 20.0	20	0.060 - 0.100
25	< 25.0	25	0.080 - 0.130

- At shoulder milling, feed per tooth fz\* for lower ae values should be converted according formula.
- For shoulder milling cutting speed Vc may be increased up to 30%.

$a_e$	$f_z^* =$
0.10 x d	$f_z \times 3$
0.25 x d	$f_z \times 2$
0.50 x d	$f_z \times 1$

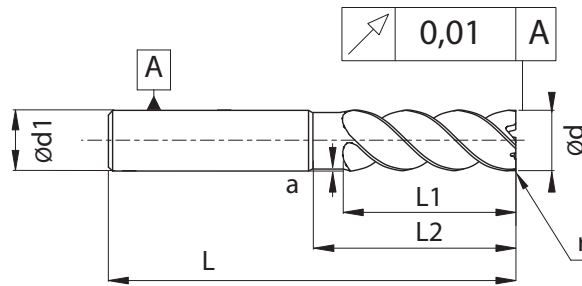


Multi Flute

Centre cutting high performance multi flute end mill for exotic materials



END MILLS



P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød (mm)	r (mm)	Ød1 (mm)	L (mm)	L1 (mm)	L2 (mm)	a (mm)	z	γ (°)	EDP No
<b>Standard</b>									
6	0.3	6	64	15	-	-	6	-	FBK0505051
8	0.5	8	64	20	-	-	6	-	FBK0503657
10	0.5	10	78	22	-	-	6	-	FBK0505052
12	0.5	12	78	28	-	-	6	-	FBK0505053
16	0.5	16	89	34	-	-	6	-	FBK0505054
20	0.5	20	102	42	-	-	8	-	FBK0505055
<b>Long</b>									
6	0.3	6	64	20	-	-	6	-	FBK0505056
8	0.5	8	78	30	-	-	6	-	FBK0505057
10	0.5	10	89	35	-	-	6	-	FBK0505058
12	0.5	12	102	40	-	-	6	-	FBK0505059
16	0.5	16	102	50	-	-	6	-	FBK0505060
20	0.5	20	125	60	-	-	8	-	FBK0505061
<b>Extra long</b>									
8	0.5	8	102	40	-	-	6	-	FBK0505062
10	0.5	10	125	60	-	-	6	-	FBK0505063
12	0.5	12	150	65	-	-	6	-	FBK0505064
16	0.5	16	150	75	-	-	6	-	FBK0505065
20	0.5	20	150	80	-	-	8	-	FBK0505066



## Cutting conditions

Centre cutting high performance multi flute end mill for exotic materials

Material group	TSR	Hardness	Cutting speed	Coolant
	(N/mm <sup>2</sup> )	HRc	Vc m/min	
P3	< 750	< 35 HRc	140 - 220	emulsion
P4	< 1000	< 35-48 HRc	100 - 180	emulsion
P4	< 1400	< 35 HRc	70 - 160	emulsion
H1		42-50 HRc	80 - 140	emulsion
M1	< 600		80 - 130	emulsion
M2	600-800	< 25 HRc	60 - 100	emulsion
M3	< 800	< 30 HRc	60 - 100	emulsion
K1	< 800		100 - 160	emulsion
S1	500-1200	25-48 HRc	40 - 60	emulsion
S2	1000-1500	25-48 HRc	45 - 70	emulsion
S3	600-1700	<48 HRc	30 - 50	emulsion
S4	900-1600	33-48 HRc	60 - 90	emulsion

### FBK0505061

**Workpiece material:**

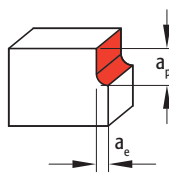
1.4401 stainless 316

	Totem
Ø	8mm
Z	6 Flutes
vc	100 m/min
n	3979 rpm
Fz	0.03 mm/t
vf	950 mm/min
ap	40 mm
ae	0.2 mm
Coolant	emulsion

Q	7.6 cm <sup>3</sup> /min
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### Advantages

- Superior surface finish!
- Excellent straightness tolerances.
- Cutting length up to 6 x D.



### Roughing

Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
6	< 20.0	< 0.48	0.035 - 0.055
8	< 40.0	< 0.64	0.045 - 0.075
10	< 60.0	< 0.80	0.070 - 0.090
12	< 65.0	< 0.96	0.080 - 0.110
16	< 75.0	< 1.28	0.100 - 0.140
20	< 80.0	< 1.60	0.120 - 0.180

### Finishing

Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
6	< 20.0	< 0.12	0.020 - 0.040
8	< 40.0	< 0.16	0.030 - 0.050
10	< 60.0	< 0.20	0.040 - 0.060
12	< 65.0	< 0.24	0.050 - 0.080
16	< 75.0	< 0.32	0.070 - 0.100
20	< 80.0	< 0.40	0.085 - 0.120

# 2 Flute

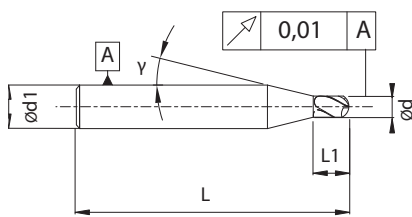
## Centre cutting high performance 2 flute ball nose for exotic materials



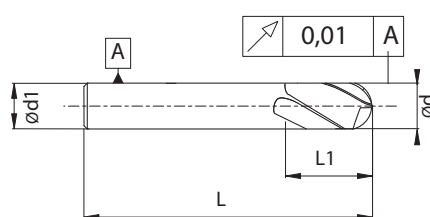
END MILLS



Micro



Standard



\* For endmills L I 100 mm.

P1-P6

K1-K2

M1-M3

S1-S4

H1

Unit : mm

Ød (mm)	r (mm)	Ød1 (mm)	L (mm)	L1 (mm)	L2 (mm)	a (mm)	z	γ (°)	EDP No
0.4	0.20	4	51	0.6	-	-	2	10	FBK0505037
0.5	0.25	4	51	0.9	-	-	2	10	FBK0505038
0.6	0.30	4	51	1.2	-	-	2	10	FBK0505039
0.8	0.40	4	51	1.5	-	-	2	10	FBK0505040
1	0.50	4	51	2	-	-	2	15	FBK0505041
1.5	0.75	4	51	3	-	-	2	15	FBK0505042
2	1.00	4	51	4	-	-	2	15	FBK0505043
3	1.50	4	51	6	-	-	2	15	FBK0505044
4	2.00	6	57	8	-	-	2	15	FBK0505045
5	2.50	6	57	10	-	-	2	15	FBK0505046
6	3.00	6	57	12	-	-	2	-	FBK0505047
8	4.00	8	63	16	-	-	2	-	FBK0505048
10	5.00	10	72	20	-	-	2	-	FBK0505049
12	6.00	12	83	24	-	-	2	-	FBK0505050



## Solid Carbide End Mills

### Cutting conditions

END MILLS

Centre cutting high performance 2 flute ball nose for exotic materials

Material group	TSR	Hardness	Cutting speed	Coolant
	(N/mm <sup>2</sup> )	HRc	Vc m/min	
P3	< 750	< 35 HRc	140 - 220	emulsion
P4	< 1000	< 35-48 HRc	100 - 180	emulsion
P4	< 1400	< 35 HRc	70 - 160	emulsion
H1		42-50 HRc	80 - 140	emulsion
M1	< 600		80 - 130	emulsion
M2	600-800	< 25 HRc	60 - 100	emulsion
M3	< 800	< 30 HRc	60 - 100	emulsion
K1	< 800		100 - 160	emulsion
S1	500-1200	25-48 HRc	40 - 60	emulsion
S2	1000-1500	25-48 HRc	45 - 70	emulsion
S3	600-1700	<48 HRc	30 - 50	emulsion
S4	900-1600	33-48 HRc	60 - 90	emulsion

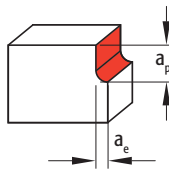
**FBK0505048**

**Workpiece material:**

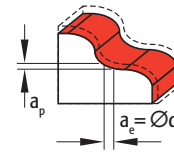
1.4462 Duplex

	Totem
Ø	8mm
Z	2 Flutes
vc	120 m/min
n	4775 rpm
Fz	0.04 mm/t
vf	385 mm/min
ap	0.1 mm
ae	0.1 mm
Coolant	emulsion

Q	2.5 Hours
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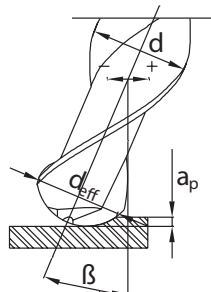
**Roughing**



**Finishing**

Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
0.4	< 0.60	< 0.12	0.004 - 0.008
0.5	< 0.75	< 0.15	0.005 - 0.009
0.6	< 0.90	< 0.18	0.006 - 0.010
0.8	< 1.20	< 0.24	0.007 - 0.012
1	< 1.50	< 0.30	0.008 - 0.015
1.5	< 2.25	< 0.45	0.012 - 0.018
2	< 3.00	< 0.60	0.016 - 0.022
3	< 4.50	< 0.90	0.018 - 0.025
4	< 6.00	< 1.20	0.020 - 0.028
5	< 7.50	< 1.50	0.025 - 0.035
6	< 9.00	< 1.80	0.028 - 0.042
8	< 12.00	< 2.40	0.030 - 0.050
10	< 15.00	< 3.00	0.040 - 0.070
12	< 18.00	< 3.60	0.050 - 0.080

Ød (mm)	ap max. (mm)	ae max. (mm)	fz (mm/tooth)
0.4	< 0.60	< 0.04	0.007 - 0.015
0.5	< 0.75	< 0.05	0.010 - 0.020
0.6	< 0.90	< 0.06	0.012 - 0.021
0.8	< 1.20	< 0.08	0.014 - 0.023
1	< 1.50	< 0.10	0.015 - 0.025
1.5	< 2.25	< 0.15	0.020 - 0.030
2	< 3.00	< 0.20	0.025 - 0.035
3	< 4.50	< 0.30	0.028 - 0.040
4	< 6.00	< 0.40	0.030 - 0.045
5	< 7.50	< 0.50	0.035 - 0.050
6	< 9.00	< 0.60	0.040 - 0.055
8	< 12.00	< 0.80	0.050 - 0.065
10	< 15.00	< 1.00	0.055 - 0.080
12	< 18.00	< 1.20	0.065 - 0.090



For the cutting speed Vc calculation the effective cutting diameter d<sub>eff</sub> has to be taken into account. See formula.

$$\beta \neq 0; \quad d_{\text{eff}} = d \times \sin \left[ \beta \pm \arccos \left( \frac{d - 2a_p}{d} \right) \right]$$