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EFFECT OF BALL BURNISHING MEDIUM ON THE SURFACE CHARACTERISTICS OF FREE MACHINING BRASS

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ABSTRACT

Burnishing is becoming a promising surface finishing process to enhance materials surface properties. The control of the various process parameters yields the desired surface characteristics in brass materials. In the current work, free machining brass specimens were burnished by Abrasive Assisted Burnishing(AAB) process and Plain Burnishing (PB) process using ball burnishing tool. Response Surface Methodology was used to design the experiments in which Burnishing Force, Speed, Feed and Number of Passes were chosen as the process parameters. The minimum surface roughness achieved by PB and AAB was 0.1451 μm and 0.1041 μm respectively. The maximum surface hardness achieved using PB and AAB on the brass specimen was 207 HV and 248 HV respectively. The ball burnishing of free machining brass by AAB resulted in better surface characteristics as compared to PB process.

INTRODUCTION

The surface properties of engineering materials play a vital role in improving the service life of the components. Surfaces with poor surface finish are conducive to crack initiation and crack propagation leading to early failure. The increased surface roughness also contributes to a higher wear rate resulting to material loss and reduced life of the parts. Traditional finishing methods such as grinding, honing etc., improve the surface finish but the residual tensile stresses in the parts post the finishing process are causes of material failure. Hence an ideal finishing process should increase the surface hardness, reduce surface roughness and induce compressive stresses in the work material and burnishing is one such process which can accomplish these conditions [1]. Burnishing process can be carried out with the help of ball burnishing or roller burnishing tool on ferrous and nonferrous materials to improve the surface characteristics using conventional machine tools [2].

In the burnishing process, a deforming element which can be either a ball or a roller rolls over the workpiece under an applied burnishing force to deform the surface irregularities. As the deforming element rolls over the work surface with pressure exceeding yield strength of the work material, regularities are redistributed making the surface smoother. The residual compressive stresses are induced as the material is plastically deformed and surface hardness is increases. The schematic diagram of the burnishing processes is shown in figure 1.

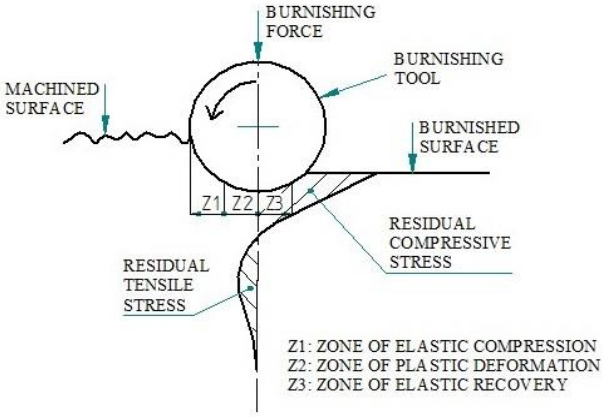


Figure 1 Schematic representation of burnishing process

A. M. Hassan et al. [3] investigated the effect of burnishing parameters on surface roughness and hardness of free machining brass. The experimental results revealed that the minimum surface roughness achieved was 0.1 µm and 60% improvement found in microhardness as compared to turned specimens. The influence of orthogonal burnishing parameters on surface characteristics was studied by M.H. El-Axir and M.M. El-Khabeery [4]. The results show that depth of penetration and time are having profound effect on responses. It was also concluded that increase in speed leads to a reduction in microhardness and out-of-roundness of the specimen decreases initially but increases at high burnishing speeds. The ball burnishing process was carried out on Al-6061 under different levels of control parameters and different burnishing orientations viz. parallel and cross- burnishing orientations by N. S. M. El-Tayeb et al. [5]. The results indicated that the burnishing speed of 330 rpm and burnishing force of 160 N produced best responses. It was also found that a decrease in ball diameter resulted in a peak improvement of 75% in surface roughness. Burnishing in parallel orientation resulted in lower friction coefficient as compared to burnishing in cross-orientation. Analytical study and experimental validation of the burnishing process was carried by Lie et al. [6] to determine the effect of elastic properties of work material on the surface roughness. AA7075 and AISI5140 work materials were used in the forms of bars and burnished on a lathe machine. It was found that the surface roughness was proportional to the 2/3 power of burnishing force in case of roller burnishing and square root of burnishing force in case of ball burnishing.

M. H. El- Axir et al. [7] replaced three adjustable jaws of moving rest in the lathe with ball burnishing attachment called centre rest burnishing tool to finish the round-machined mild steel parts with high accuracy. Mieczyslaw Korzynski et al. [8]constructed prototype of centerless burnishing structure and examined its effect on a shaft made of 41Cr4 steel workpiece. F. Gharbi et al. [9] studied the effect of ball burnishing process on surface quality and service properties of AISI1010 steel hot-rolled plates. The tensile strength tests have shown that the ductility increased by 49%. A reduction in residual stresses up to 420 MPa was achieved in feed direction and 155 MPa in the cross feed direction. Tareq A. Abu Shreehah [10] developed the elastic ball burnishing tool and studied the effect of parameters such as feed, speed, force and number of passes on surface roughness, surface hardness and form accuracy. The optimum range of parameters which are capable of producing better surface roughness and surface hardness was high spindle speed and number of passes (Namely at 75 m/min and 4 passes), low feed rate (0.05 mm/rev) and low burnishing force (up to 300 N).V. Franzen et al. [11] employed the roller burnishing as finishing process to the coated surfaces to study the tribological properties of coated and finished of DP600 sheets. It is shown that roller burnishing parameters have a significant effect on the surface topology of the friction elements and their tribological properties.

The polyethylene (LDPE) are end milled and burnished to decrease surface roughness values to 0.57 µm. Microhardness and scratch resistance values of burnished surface are also improved with respect to milled specimens [12]. Burnished Titanium (Ti-6Al-4V) alloy exhibited reduction in specific wear rate and coefficient of friction by 52% and 64% respectively [13]. The improvement in corrosion resistance of AISI 1045 steel with burnishing is reported [14]. The ball burnishing process applied to Al7175 in presence of alumina nanoparticles Nano fluid showed improvement in surface characteristics when compared with dry burnishing [15]. Recent study [16] concentrating the energy saving during burnishing revealed 39.50% energy saving during burnishing of H13 steel. The literature study conducted revealed that the role of abrasive particles in burnishing process is not established. Hence in this paper the burnishing process is carried out in presence of abrasive particles and compared with plain burnishing process.

METHODOLOGY

Plain Burnishing and Abrasive Assisted Burnishing processes were carried out on free machining brass in which burnishing force, speed, feed and number of passes were the control parameters. Surface roughness and Surface hardness were measured on the burnished specimen at three locations and the average of the three results was taken as the final result for the test condition. The variation between the three results of a given test condition was found to less than 1% in all cases indicating a good control of the process parameters. Each of the 4 control parameters had 5 levels as given in Table 1.

Table 1 Process parameters levels

Process parameter	Levels				
	2	1	0	-1	-2
Force, kgf (N)	25 (245.25)	20 (196.2)	15 (147.15)	10 (98.10)	5 (49.05)
Speed, rpm	910	735	560	385	210
Feed, mm/rev	0.207	0.163	0.119	0.076	0.03
Number of passes	5	4	3	2	1

Response Surface Methodology was used for the Design of Experiments and the experimental runs and the measured responses on the burnished part in PB and AAB conditions. The brass specimen was initially turned for size of $\phi 18 \times 150$ mm and grooves were cut at a distance of 30 mm length on the workpiece. Each of the 30 mm length on the specimen was used for different burnishing conditions. The surface roughness was measured using Tally Surf Roughness Tester with a sampling length of 2.5 mm and the surface hardness was measured using Vickers Hardness tester with diamond indenter. The residual stress in the brass specimen was measured using XRD method.

RESULT AND DISCUSSION

The initial surface roughness and surface hardness on the turned brass specimen were found to be 2.7838 μm and 165 HV respectively. The residual tensile stress of +230.8 MPa was found in the turned brass specimen. The burnishing processes were carried as per the experimental design and the corresponding responses measured was given Table 2.

Table 2 Experimental runs and Responses

Sl. No.	Force (kgf)	Speed (rpm)	Feed (mm/min)	No. of Passes	Surface Roughness, Ra (μm)		Surface hardness, HV	
					Ra (PB)	Ra (AAB)	(PB)	(AAB)
1	10	735	0.163	4	0.8791	0.8233	189	230
2	10	385	0.163	4	0.9310	0.9247	197	238
3	15	910	0.1195	3	0.3332	0.5469	178	205
4	15	560	0.1195	3	0.2006	0.1099	188	219
5	10	735	0.076	2	0.5172	0.4689	171	199
6	10	385	0.076	4	0.3194	0.2475	190	228
7	15	560	0.1195	3	0.2284	0.1085	187	216
8	25	560	0.1195	3	0.1891	0.3080	196	234
9	10	385	0.163	2	0.9587	0.8900	185	216
10	20	385	0.076	4	0.4894	0.4076	207	248
11	15	560	0.1195	3	0.2198	0.1041	187	219
12	15	210	0.1195	3	0.3480	0.3800	196	234
13	15	560	0.1195	3	0.2092	0.1127	188	219
14	20	735	0.076	2	0.2754	0.4633	189	226
15	15	560	0.1195	1	0.4936	0.5352	178	206
16	15	560	0.1195	3	0.2305	0.1154	187	216
17	15	560	0.0325	3	0.2200	0.2400	191	229
18	20	735	0.163	4	0.1506	0.3420	189	228
19	15	560	0.2065	3	0.6574	0.7814	185	217
20	20	385	0.163	4	0.3481	0.4100	199	235
21	10	385	0.076	2	0.3867	0.2666	180	211
22	15	560	0.1195	3	0.2134	0.1107	187	220
23	15	560	0.1195	3	0.2049	0.1055	187	219
24	20	385	0.163	2	0.1451	0.2226	188	218

25	20	385	0.076	2	0.2838	0.2700	199	238
26	20	735	0.163	2	0.1496	0.3100	175	208
27	10	735	0.163	2	1.2133	1.0284	171	201
28	20	735	0.076	4	0.2907	0.4499	200	242
29	15	560	0.1195	5	0.4191	0.5399	204	245
30	5	560	0.1195	3	1.0196	0.8740	177	207
31	10	735	0.076	4	0.3139	0.2900	182	211

ANOVA was computed for the responses and for both PB and AAB and it was found that Burnishing force was the most significant factor contributing to the improvement in the surface roughness and surface hardness followed by burnishing feed, speed and number of passes. The contribution of burnishing force is high since it effects the deforming of the irregularities on the specimen during the burnishing process. The regression equations were developed for the surface roughness and surface hardness for both PB and AAB conditions and are given in Table 3. The high values of R-Sq., R-Sq.(pred.) values for the experiments carried out indicate that the mathematical models have a good fit to the experimental data and hence these equations can be used to predict the response in the range of the selected parameters taken in this study.

Table 3 Regression Equations for surface roughness and surface hardness in PB and AAB conditions

Burnishing Conditions	**Regression Equations**	**R-Sq.**	**R-Sq. (adj.)**	**R-Sq. (pred.)**
Plain Burnishing	Surface roughness, Ra (μm) = 0.968 – 0.07028 force + 0.000303 speed + 8.153 feed - 0.4075 nop + 0.004013 force*force + 0.000001 speed*speed + 31.13 feed*feed + 0.06331 nop*nop - 0.000052 force*speed - 0.8594 force*feed + 0.01322 force*nop + 0.000754 speed*feed - 0.000298 speed*nop - 0.155 feed*nop	99.7%	99.43%	98.39%
	Surface hardness, HV = 153.68 + 3.681 force - 0.02721 speed + 198.2 feed – 3.37 nop - 0.00744 force*force - 0.000002 speed*speed + 99.9 feed*feed + 0.939 nop*nop - 0.000071 force*speed – 18.103 force*feed - 0.0875 force*nop - 0.0903 speed*feed + 0.00464 speed*nop + 21.55 feed*nop	99.65%	99.34%	98.23%
Abrasive Assisted Burnishing	Surface roughness, Ra (μm) = 1.920 – 0.09655 force - 0.001600 speed + 4.210 feed - 0.6188 nop + 0.004566 force*force + 0.000003 speed*speed + 49.72 feed*feed + 0.10079 nop*nop - 0.000002 force*speed - 0.7757 force*feed + 0.00890 force*nop - 0.003481 speed*feed - 0.000252 speed*nop + 0.176 feed*nop	99.54%	99.13%	97.35%
	Surface hardness, HV = 213.5 + 3.832 force - 0.0913 speed + 31.0 feed – 7.73 nop + 0.0317 force*force + 0.000018 speed*speed + 749 feed*feed + 2.043 nop*nop + 0.001214 force*speed – 29.02 force*feed - 0.212 force*nop + 0.0575 speed*feed + 0.00393 speed*nop + 47.4 feed*nop	98.32%	96.85%	91.65%

The main effects and interaction effects plots for the surface roughness after PB and AAB are shown in the Figures 2-5. The main effects contribute for 72.31%, 76.10% of the variations in the surface roughness in PB, AAB respectively. With the increase in force, the surface roughness decreases gradually and then increase in both the burnishing conditions due to complete deformation of the surface irregularities at higher burnishing forces. At high forces, the deformation causes the surfaces to be pulled along with the tool and this may lead to increased surface roughness. The variation of roughness with speed is minimal in PB when compared to AAB. In AAB, the surface roughness is minimum at a particular speed and beyond which the roughness increases. At lower speeds, there was sufficient time for material to deform and thus the surface roughness increased but at too low speed. The deforming element may be rolling on the surface which leads to higher surface roughness. As speed increases, the deforming element rolls over the surface and thus improves the surface but at higher speeds, the time for the deformation is reduced and thus the surface roughness is found higher.

The surface roughness increases with increasing feed rate beyond a certain feed rate in both PB and AAB because, at low feed rates, the overlapping of the burnishing passes results in the improved surface. Up to 2 passes the surface roughness decreases and then as the number of passes was increased the surface roughness increase in both PB and AAB. When the number of passes was low, the deformation will be gradual and be complete in 2 passes and with increased number of passes, the deformed material may be dragged along with the deforming element leading to poor surface roughness. The interaction between force and feed contributes to 79.09%, 85.83% of the total interaction effects in PB, AAB respectively and the variation in responses due to other interaction is very less.

The main effects plot and interaction plots of surface hardness for PB and AAB are shown in the figures 6-9. From the plots, it is observed that feed has little effect on the surface hardness and the other three selected parameters have higher effect on the surface hardness in the range of study. The main effects of the control parameters contribute to 87.93%, 83.69% in the variations of the surface hardness and the interaction of the force and feed contributes to 87.53%, 84.68% of the variations in surface hardness due to interaction effects of the control parameters. The effects of interaction between other parameters are very less.

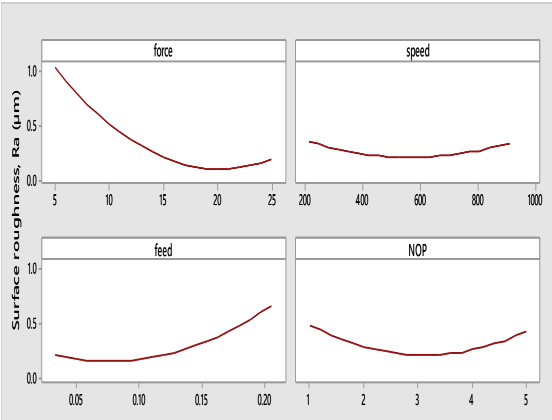


Figure 2 Main effect of parameters in PB

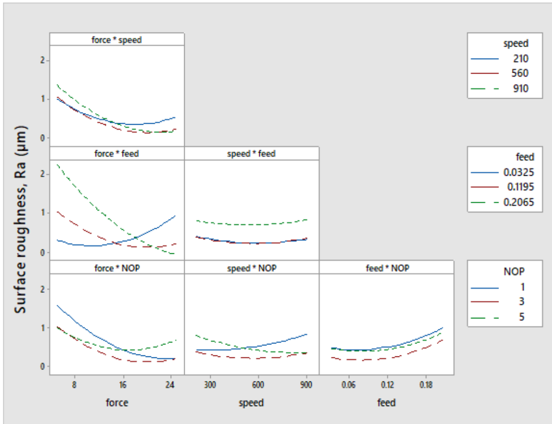


Figure 3 Interaction effects of parameters in PB

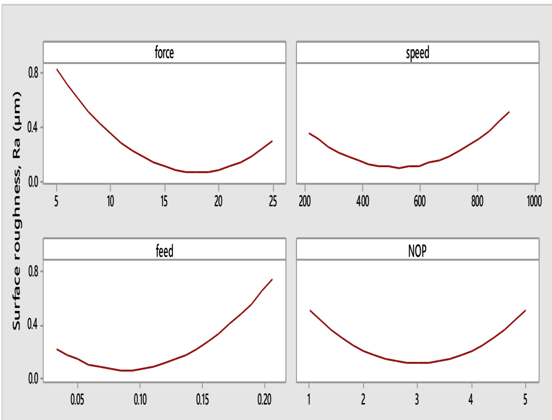


Figure 4 Main effect of parameters in AAB

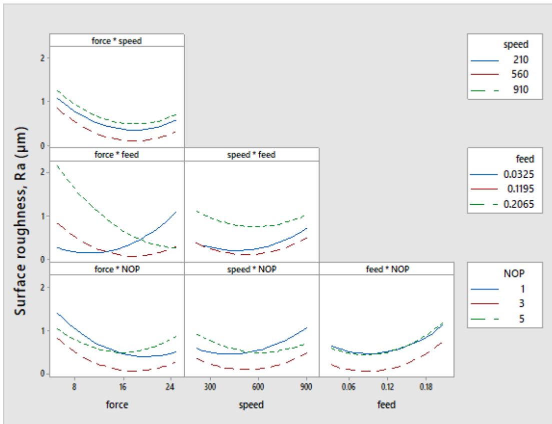


Figure 5 Interaction effects of parameters in AAB

When the burnishing force increases, the plastic deformation is higher and work hardening of the material is complete resulting in high surface hardness at higher forces. With the increase in the speed of the heat generated in the burnishing zone is higher and the material softens resulting in higher surface roughness due to improper deformation and the higher temperature results in lower hardness at the surface of the workpiece. When number of passes of burnishing on the work material, the strain hardening is continuous increases resulting in higher surface hardness.

The range of surface roughness achieved through PB, AAB was 0.1451-0.9587μm, 0.1041-0.9247μm respectively which are less than the roughness then plain turned specimen. Thus the burnishing methods reduced the surface roughness in all burnishing conditions. The lowest surface roughness in the test cases was achieved in AAB. The range of surface hardness achieved through PB, AAB was 171-207 HV, 201-248 HV respectively. The surface hardness of burnished samples was higher than the turned sample in all test conditions. The highest surface hardness was achieved through AAB. The use of AAB has resulted in lowest and surface roughness and the highest hardness in the burnished samples. The residual stresses were found to be in the range of -10MPa to -380.8 MPa for both PB, AAB samples. The SEM images of turned (a) and of the samples with lowest surface roughness after PB(b), AAB (c) are shown in figure 10. The images indicate a smooth surface without much irregularities indicating the effective deformation of the surface irregularities.

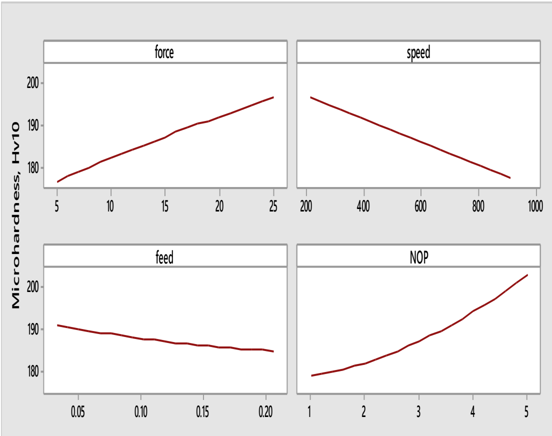


Figure 6 Main effect of parameters in PB

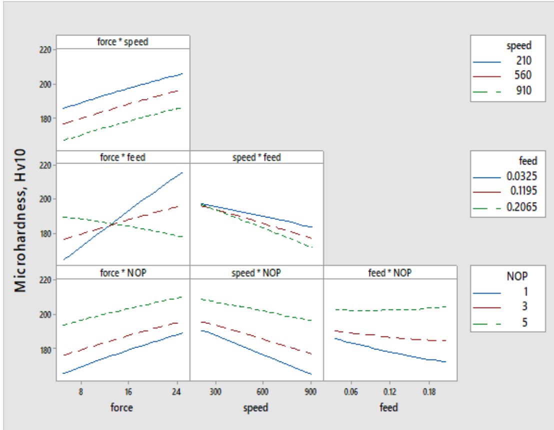


Figure 7 Interaction effect of parameters in PB

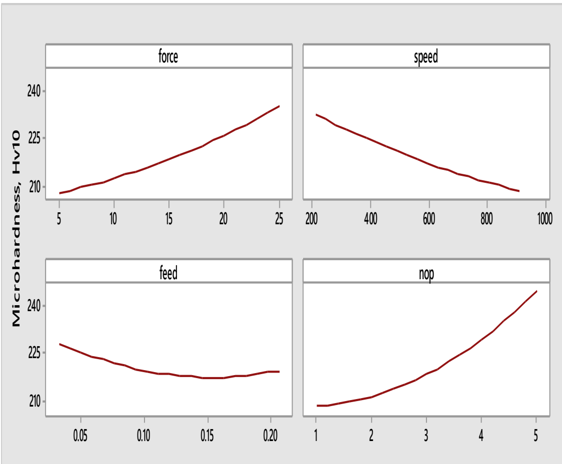


Figure 8 Main effect of parameters in AAB

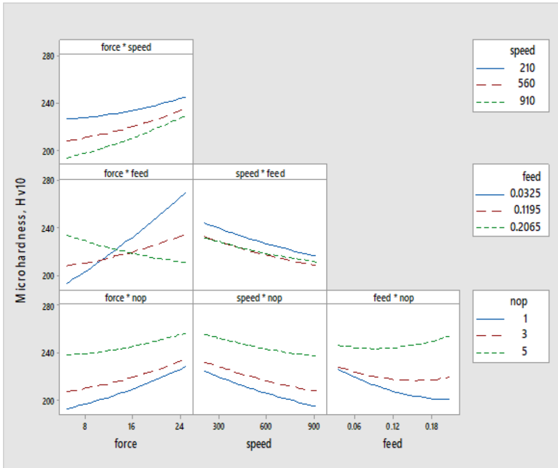
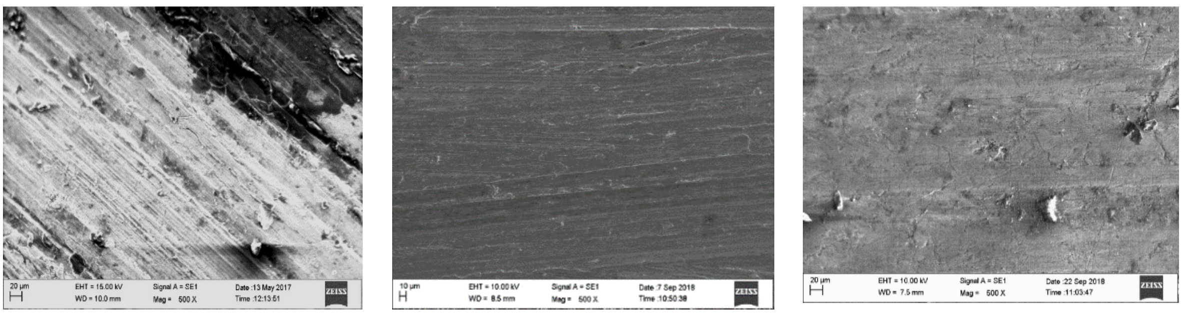


Figure 9 Interaction effect of parameters in AAB



(a) (b) (c)

Figure 10 SEM images of turned (a) and ball burnished brass surfaces in PB(b) and AAB (c) conditions

CONCLUSIONS

Plain burnishing (PB) of the brass specimen using ball burnishing tool resulted in 95% and 25% improvement in surface roughness and surface hardness respectively in comparison to the turned specimen. An improvement of 96% and 50% was observed in surface hardness and surface roughness on the Abrasive Assisted Burnishing(AAB) specimen in comparison to the turned specimen. The minimum surface roughness achieved using PB, AAB was 0.1451 µm, 0.1041 µm respectively and the maximum surface hardness achieved using PB, AAB was 207 HV, 248 HV respectively. PB and AAB have resulted in residual compressive stresses in the brass specimen which will improve the service life of the burnished components.

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