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Research Paper

OPTIMIZATION OF CUTTING PARAMETERS OF AISI H13 WITH MULTIPLE PERFORMANCE CHARACTERISTICS

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The selection of optimum process parameters plays a significant role to ensure quality of product. If more than one attribute comes into consideration it is very difficult to select the optimal setting which can achieve all quality requirements simultaneously. The present study response surface methodology is applied for optimization of process parameters for machining of hard material by CNC end milling. This study investigates the multi-response optimization of end milling process for an optimal parametric combination to yield the tool wear and surface roughness. It deals with the effects of three input process parameters chosen on the machining of AISI H13 by using design of experiment. The main objectives of this work are to investigate the process parameters for surface roughness and tool wear in end milling to obtain the optimal surface roughness and tool wear using Response Surface Methodology and to recommend the best machining parameters that contributes to the optimum surface roughness and tool wear value.

Keywords: Response Surface Methodology (RSM), Mathematical modeling, Surface roughness (Ra), Tool wear and surface plots

INTRODUCTION

The advance of modern technology and a new generation of manufacturing equipment, particularly Computer Numerical Control (CNC) machine, have brought enormous changes to the manufacturing sector. Generally, the handbook or human experience is used to select convenient machine parameters in manufacturing industry. In process planning of conventional milling, selecting reasonable milling parameters is necessary to satisfy requirements involving machining economics, quality and safety. The machining parameters in milling operations consists of cutting speed, depth of cut, feed rate and number of passes. These machining parameters significantly impact on the cost, productivity and quality of machining parts. The

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effective optimizations of these parameters affect dramatically the cost and production time of machined components as well as the quality of final products. In order to get specified surface roughness, selection of controlling parameters is necessary. There has been a great many research developments in modeling surface roughness and optimization of the controlling parameters to obtain a surface finish of desired level since only proper selection of cutting parameters can produce a better surface finish. But such studies are far from complete since it is very difficult to consider all the parameters that control the surface roughness for a particular manufacturing process. In CNC milling there are several parameters which control the surface quality. The analysis of surface roughness on CNC end milling process is a big challenge for research development. Several factors involved in machining process have to be optimized to obtain a desired surface quality. In this study, three machining parameters are considered viz. spindle speed, feed rate and depth of cut. Computer Numerical Control (CNC) is one in which the functions and motions of a machine tool are controlled by means of a prepared program containing coded alphanumeric data.

Hard machining is machining of parts with a hardness of above 45 HRC, although most frequently the process concerns hardness of 58 to 68 HRC. The work piece materials involved include various hardened alloy steels, tool steels, case-hardened steels, super alloys, nitride irons and hard-chrome coated steels, and heat-treated powder metallurgical parts. It is mainly a finishing or semi-finishing process where high dimensional, form, and surface finish accuracy have to be achieved. Since its broader introduction in the mid 1980s in the form of hard turning, hard machining has evolved considerably in various machining operations as milling, boring, broaching, hobbling, and others. Developments of suitable rigid machine tools, super hard cutting-tool materials and special tool (toolholders) designs, and complete set-ups has made the metal cutting of hardened parts easily accessible for any machine shop. The conventional solution to finishing hardened steel parts has been grinding, but there are a number of clear benefits to the machining of hard parts with a cutting tool. These have justified many existing applications that are growing in number, especially involving turning, boring, and milling. Hard turning was early recognized and pioneered by the automotive industry as a means of improving the manufacturing of transmission components. Gear-wheel bearing surfaces are a typical example of early applications converted from grinding to hard machining using inserts in polycrystalline Cubic Boron Nitride (PCBN). Case-hardened steel components are typical, often having a hardness-depth of just over 1 mm, giving it a wear resistant case and a tough core. Components that make use of this combination of material properties include gears, axles, arbors, camshafts, cardan joints, driving pinions, and link components for transportation and energy products, as well as many applications in general mechanical engineering.

Kang *et al.* (2001) carried out a comparative study, evaluating the characteristics of machined steel with a hardness of 28 HRc in a workpiece of planar geometry, varying the angle of inclination to 15, 30, and 45 degrees, using four possible cutting strategies. They used a solid carbide ball nose end mill coated with TiAlN, having a diameter of 10 mm and two cutting edges. They presented a qualitative and quantitative analysis of the surfaces obtained, showing images of the surface texture and graphs of roughness for each condition. The texture obtained for each condition shows the influence of the cutting strategy employed. These authors reported that the strategies employing an ascending cut, with the tool executing the cut from the base of the inclined plane and going up, presented lower values of surface roughness and a more homogeneous texture when compared with the descending strategies.

Although the machining of hardened steels presents difficulties during machining, Jung and Zheng (2003) showed that it offers advantages in the process and the final machined product, providing improvement in surface quality and dimensional control. A final machining after the thermal treatment, with the material already at the final work hardness, prevents recurrent problems related to the hardness, such as possible workpiece distortion and dimensional variation. One of the more basic and predominant geometric forms in the manufacture of molds and die cavities is the inclined plane. To simulate a finishing condition, geometry of low complexity was adopted, defined as an inclined surface, in one workpiece of definite and reduced dimensions. The main doubt in the machining of this geometry is to know what the best strategy is, defined as the tool trajectory. This includes the workpiece inclination, defined as the angle formed between the tool and a plane normal to the axis of the tool. We consider the ball-nose end mill, which is the type of tool most appropriate for finishing processes on surfaces with complex forms. In the literature, studies of the machining of inclined planes are restricted mainly to evaluating the life of the tool and varying the cutting conditions (feeds and speeds). A smaller number of papers go beyond this and consider the cutting strategies, comparing them with the surface quality obtained. The strategies are defined by the feed and cutting directions, being vertical or horizontal with respect to the plane, and with a direction that can be ascending (upward) or descending (downward).

Toh (2004) carried out an analysis of the topography of surfaces machined on AISI H13 with hardness 52 HRc. The analysis evaluated different cutting strategies and cutting path orientations, using a planar geometry, inclined at 75°, simulating a finishing process. They used a solid tungsten carbide ball nose end mill, with TiAlN coating, with a diameter of 10 mm and six cutting edges. The objective was to understand the surface texture generated by certain cutting path orientations in a material of difficult machinability. An analysis of the topography resulted in threedimensional graphs of the roughness profile and allowed a determination of the best orientation for obtaining texture of better quality. In conclusion, Toh reported that the strategy involving an ascending vertical cut provided the best results.

According to Tabenkin (2005), the finishing or texture can be described in terms of the number and direction of the valleys and peaks that compose a surface. The analysis of the surface, in practical terms, can be made in terms of three basic components: roughness, undulation, and form. Generally, the three exist simultaneously, overlapping, although in many situations, it is desirable to examine each condition independently.

Aman and Hari (2005) reviewed various linear and non linear optimization techniques were studied in detail and relative advantages are also discussed and inferred for the non linear optimization methods are the most suited for the optimization of machining processes. The suggestion of the authors is to follow appropriate set of optimization methods based on the problem on hand and also to use a base statistical method to get the initial basic feasible solution and a non linear like genetic algorithm according to the respective problem and solution requirements.

DESIGN OF EXPERIMENTS

The design of experimentation has a significant role on the number of experiments needed. Therefore cutting experiments have to be designed In this study a 3 level face centered cubic design were performed to obtain the surface roughness values a total of 20 experiments are conducted at 3 levels for the three input variables speed, feed, depth of cut. Table 1 shows the actual design data and Table 4 shows the measured Ra and tool wear values with coaded parameters.

Table 1: Recommended Value of Input Parameters

Factors	Unit	Level –1	Level 0	Level 1
A. Speed	rpm	3500	4000	4500
B. Feed Rate	mm/t	0.01	0.03	0.05
C. Depth of Cut	m m	0.20	0.35	0.5

EQUIPMENTS AND MATERIAL

The machine used for the milling tests was a ‘Surya VF30CNC VS’ CNC end milling machine having the control system ‘FANUC-Oi mate model C’ with a vertical milling head. For generating the milled surfaces, CNC part programs for tool paths were created with specific of this Firtz commands. Manufacturer CNC machine is Bharat Werner Ltd.

Work Piece Material

The work piece material used for present work was AISI H13 alloy steel. The chemical composition of AISI H13 is given in Table 2. The hardness of the material is found around 50 HRC using SAROJ Hardness Testers (Model – RAB-250) before start of machining.

Table 2: Chemical Composition (wt%) of AISI H13

Element	Weight (%)	Element	Weight (%)
C	0.36	Cr	5.00
Si	1.00	Mo	1.22
Mn	0.40	V	0.90

Table 3: Mechanical Properties of H13

Properties	Measured Value
Brinal Hardness	50 HRC
Density	7760 kg/m^3
Ultimatetensile Strength	1610 MPa
Liquidus Temperature	1727 k

Tool

Commercially available CVD coated carbide tools have been used for the present investigation. The tools used are flat end mill cutters and the tools are coated with TiAIN coating.

Details of the inserts are given bellow:

Manufacturer : Mitsubishi material cop.

Code : A0MT123608PEER-M

Grade : VP15 TF

Rake angle (α_n) = 11°

The insert were fitted to a compatible cutter of diameter 20 mm from the same manufacture, i.e., Mitsubishi material cop. Details of the high performance cutter used during the experiments are given bellow:

Cutter code : APX3000 R202SA20SA

No. of teeth : 2 Nos

Maximum ramping angle : 9°

Surface Profilometer

Surface roughness was measured using the "MarSurf PS1" surface profilometer manufactured by Mahr GmbH Gottingen as shown in Figure. The arithmetic average roughness values (Ra) was measured by this instrument. The surface finish of the machined H13 steel block was measured after every machining using the profilometer.

Tool Makers Microscope

A Tool Makers Microscope was used to measure the flank wear of the insert. This kind of microscope is mainly used in micro system technology, in the automotive industry and for metallographic analysis.

MEASUREMENT OF SURFACE ROUGHNESS AND TOOL WEAR

Surface roughness and tool wear is measured after each run of experiment. Details of measurement techniques for the measuring surface roughness and tool wear are given individually in next article.

Surface finish values (Ra—arithmetic average) was measured using a stylus profilometer (Mar Surf PS1). Calibration of the instrument automatic of the roughness width cut off based on the roughness values expected. A total of 60 readings were taken to determine the average surface roughness of cut, i.e., 1 reading in the center of the block and 2 readings at a distance of 5 mm from the right side.

Table 4: Experimental Results of Roughness and Tool Wear

Coaded Input Parameters			Ra (µm)	Tool Wear (mm)
Sped	Feed	Doc		
1	1	–1	0.25	0.0300
–1	1	–1	0.435	0.0251
0	–1	0	0.175	0.0304
0	0	0	0.311	0.0345
0	1	0	0.365	0.0415
1	–1	–1	0.111	0.0200
0	0	0	0.261	0.0349
–1	0	0	0.322	0.0318
–1	1	1	0.452	0.0510
0	0	0	0.255	0.0350
1	1	1	0.235	0.0520
–1	–1	–1	0.265	0.0135
1	–1	1	0.060	0.0450
0	0	0	0.251	0.0350
1	0	0	0.162	0.0381
0	0	1	0.241	0.0475
0	0	0	0.253	0.0349
0	0	–1	0.260	0.0230
–1	–1	1	0.237	0.0385
0	0	0	0.175	0.0385

Statistical Analysis

A response surface model was designed and analyzed using design expert software

Table 5: Analysis of Variance (ANOVA) for Surface Roughness (Ra)

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Regression	9	0.162415	0.018046	0.018046	18.37	0.000
Linear	3	0.159699	0.053233	0.053233	54.18	0.000
Speed	1	0.079745	0.079745	0.079745	81.16	0.000
Feed	1	0.079032	0.079032	0.079032	80.43	0.000
Doc	1	0.000922	0.000922	0.000922	0.94	0.356
Square	3	0.000888	0.000888	0.000296	0.30	0.824
Speed*Speed	1	0.000016	0.000319	0.000319	0.32	0.581
Feed*Feed	1	0.000858	0.000816	0.000816	0.83	0.384
Doc*Doc	1	0.000014	0.000014	0.000014	0.01	0.907
Interaction	3	0.001828	0.001828	0.000609	0.62	0.618
Speed*Feed	1	0.000630	0.000630	0.000630	0.64	0.442
Speed*Doc	1	0.000378	0.000378	0.000378	0.38	0.549
Feed*Doc	1	0.000820	0.000820	0.000820	0.83	0.382
Residual Error	16	0.009826	0.009826	0.000983		
Lack-of-Fit	5	0.000330	0.000330	0.000066	0.03	0.999
Pure Error	5	0.172241	0.009496	0.001899		
Total	**19**	**0.172241**				

Note: S = 0.0313461, PRESS = 0.0148926.

Table 6: Analysis of Variance for Tool Wear

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Regression	9	0.001846	0.001846	0.000205	404.77	0.000
Linear	3	0.001834	0.001834	0.000611	1206.70	0.000
Speed	1	0.000064	0.000064	0.000064	125.34	0.000
Feed	1	0.000272	0.000272	0.000272	537.80	0.000
Doc	1	0.001498	0.001498	0.001498	2956.96	0.000
Square	3	0.000003	0.000003	0.000001	1.84	0.203
Speed*Speed	1	0.000002	0.000001	0.000001	2.39	0.157
Feed*Feed	1	0.000000	0.000000	0.000000	0.61	0.451
Doc*Doc	1	0.000000	0.000000	0.000000	0.72	0.417
Interaction	3	0.000009	0.000009	0.000003	5.76	0.015
Speed*Feed	1	0.000006	0.000006	0.000006	12.44	0.005
Speed*Doc	1	0.000002	0.000002	0.000002	3.75	0.081
Feed*Doc	1	0.000001	0.000001	0.000001	1.09	0.321
Residual Error	10	0.000005	0.000005	0.000001		
Lack-of-Fit	5	0.000005	0.000005	0.000001	22.3	0.02
Pure Error	5	0.000000	0.000000	0.000000		
Total	**19**	**0.001851**				

Note: S = 0.000711801, PRESS = 0.0000615658.

Table 5 shows the Analysis of Variance ANOVA was carried out to determine the effect of cutting parameters on the surface roughness and analysis of variance for tool wear is shown in Table 6.

R-Sq = 94.30% R-Sq(Pred) = 91.35% R-Sq(Adj.) = 89.16%

The mathematical relationship for correlating the surface roughness using uncoded data and the considered process variables has been obtained as follows:

Ra = 0.251709 – 0.089300**SPEED*

+ 0.088900*FEED – 0.009600 * DOC 0.0107727*SPEED*SPEED

+ 0.0172273*FEED*FEED

– 0.00227273*DOC*DOC

– 0.008875*SPEED*FEED

– 0.006875*SPEED*DOC

+ 0.01012*FEED*DOC ...(1)

R-Sq = 99.73% R-Sq(Pred) = 96.67% R-Sq(Adj.) = 99.48%

Multi Objective Optimization

In this present investigation, an attempt has been made to optimize simultaneously the surface roughness and tool wear after machining of hard material namely AISI H13. Therefore, a multi objective simultaneous optimization technique is used by incorporating response surface methodology to find out the optimal solution as combination of input process parameters as shown design of experiments. We have seen the effect of input parameters on surface roughness and tool wear. Now using RSM and desirability analysis for optimization of process parameters and we find the optimal process parameters for the surface roughness and tool wear.

Hence we find the optimal process parameters for minimum surface roughness and minimum tool wear after machining the H13 steel with recommended cutting conditions.

Table7: Optimal Value of Process Parameters for Surface Roughness and Tool Wear

Sped (rpm)	Feed (mm/ Tooth)	DOC (mm)	Ra (μm)	Tool Wear (mm)	Desira-bility
4500	0.01	0.2	0.113166	0.020667	0.984655

EFFECT OF PROCESS PARAMETERS ON Ra AND TOOL WEAR

To visualize the influence of the designed process parameters over the two response variables and also to find their nature of variations with respect to designed parameters three dimensional surface plots have been developed as shown in Figures 1 to 6. The surface plots physically represent the

Figure 1: Surface Plot of Ra with Respect to Speed and Feed

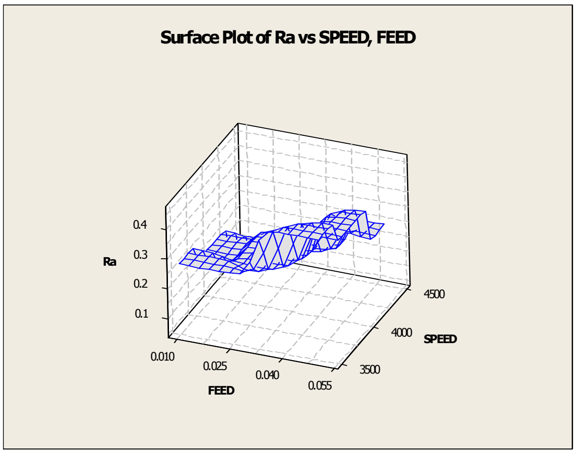


Figure 2: Surface Plot of Ra with Respect to Feed and Doc

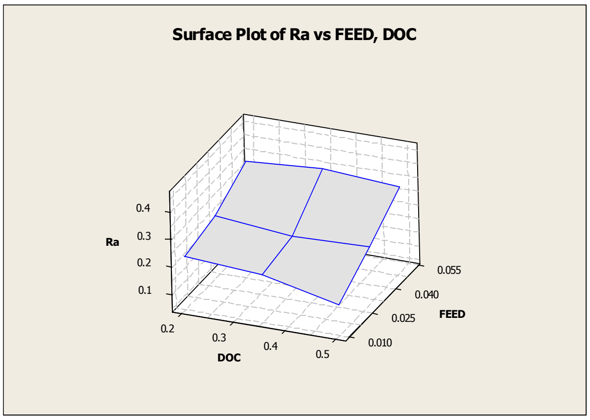


Figure 3: Surface Plot of Ra with Respect to Speed and Doc

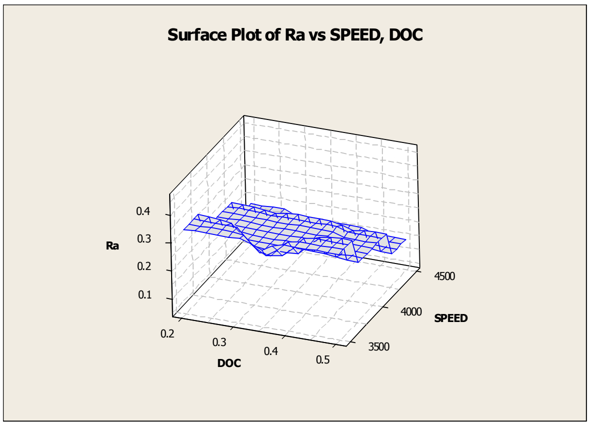


Figure 4: Surface Plot of Tool Wear with Respect to Speed and Feed

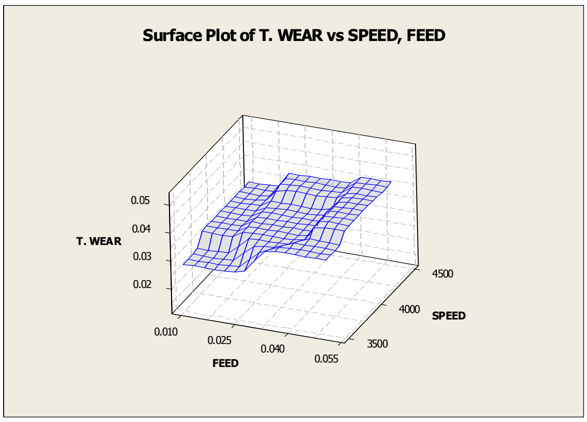


Figure 5: Surface Plot of Tool Wear with Respect to Feed and Doc

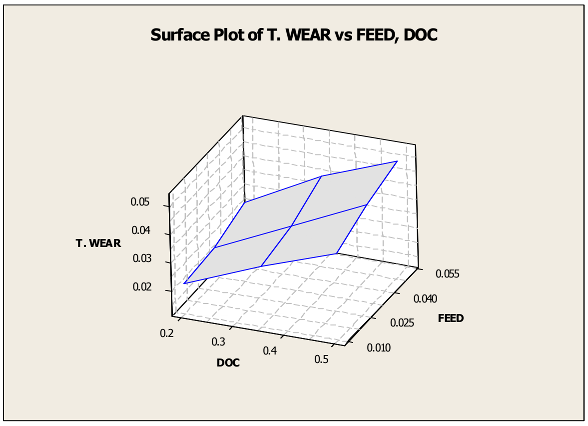
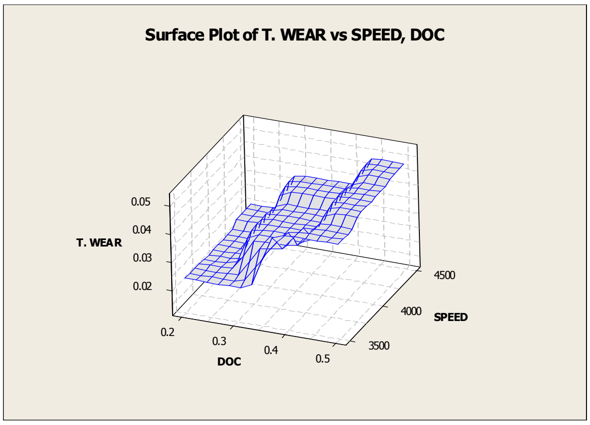


Figure 6: Surface Plot of Tool Wear with Respect to Speed and Doc



variation of the roughness and tool wear parameters with respect to cutting parameters. In each of the surface plots, two cutting parameters are varied simultaneously along X and Y axes while the response parameters are recorded along Z axis.

In above surface plot surface roughness is shown in Z axis with respect to speed and feed. In this surface plot value of surface roughness is increased with increase in feed rate and it is decreased with increased in spindle speed.

The surface plot graph is showing the surface roughness parameters in Z-axis corresponding to depth of cut (X-axis) and feed rate (Y-axis). We see that surface roughness is increased with increase in feed rate but there are slightly changes in surface roughness with increasing the depth of cut as shown in above surface plot.

From Figure 3 it is clear that at high spindle speed the value of surface roughness is very small. For the some region depth of cut is increased for the same region of spindle speed, we observe that value of surface roughness is increased. But at higher spindle speed and depth of cut the value of surface roughness is minimum.

From Figure 4 the surface plot shows the variations of tool wear with respect to spindle speed and feed rate. We observe that the value of tool wear is increased with increase in spindle speed and feed rate respectively. From the above surface plot we see that tool wear is at minimum level when feed rate and spindle speed is minimum.

From above Figure 5 we see that the value of tool wear is increased with increase in depth of cut and feed rate respectively. In the above surface plot we found that the minimum tool wear at minimum level of depth of cut and feed rate.

The surface plot of tool wear with respect to spindle speed and depth of cut shows the variations of tool wear. We observe that with increase in speed tool wear is increased and also with increase in depth of cut tool wear is increased.

It could be easily notice that, nature of variations for surface roughness and tool wear along with the change in designed process parameters are highly identical. From above surface plots we see that the with increase in spindle speed value of Ra decreased while tool wear rate is increased. Similarly when doc and feed rate is increased both tool wear and surface roughness is increased.

Optimal Process Parameters with Respect to Surface Roughness and Tool Wear

We have already seen the optimal process parameters in individual consideration. After analyzing the process parameters for surface roughness and tool wear individually we again optimize the process parameters for surface roughness and tool wear together. Hence we find the optimal process parameters using RSM which is shown in Table 8.

Table 8: Optimal Value of Process Parameters for Surface Roughness and Tool Wear

Sped (rpm)	Feed (mm/ Tooth)	DOC (mm)	Ra (µm)	Tool Wear (mm)
4500	0.01	0.2	0.113166	0.020667

CONCLUSION

The experiments were conducted on a vertical milling machine for the machining of AISI H13 steel. The tool used for the machining operation is a carbide coated tool. In this study, the effect of independent variables speed, feed, depth of cut and cutting condition and their interactions were studied in detail on two dependant variables, namely, surface roughness and tool wear. The response surface roughness and tool wear were studied and optimized using response surface methodology. During the present investigations, experiments were carried out using response surface design.

We have all ready seen the effect of process parameters on the surface roughness and tool wear using surface plot. We observed that surface roughness is increased with increase in feed and depth of cut while it is decreased when spindle speed is increased. Similarly tool wear is observed minimum when spindle speed is less for a particular run.

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