Effect of Surface Roughness of Roller Burnishing Process on 20MNCR5 Steel

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Abstract *Burnishing process is used to smooth the surface of 20MnCr5 steel. The surface roughness of the steel is influenced by the burnishing parameters such as number of passes, feed, speed, and depth of penetration. The results show that the initial roughness is the most important factor affecting the surface finish. To reduce the roughness, it is necessary to optimize the process parameters. In this paper, the effect of burnished parameters on the surface finishing and wear resistance of the mechanical components is investigated. Results show that burnishing process parameters have a significant impact on surface finish, yield strength, fatigue resistance, wear resistance, surface hardness, tensile strength and corrosion resistance. The ANOVA table shows that the interaction between no. of passes and feed, feed and deep of penetration, condition is significant towards surface roughing. The percentage contribution pie chart indicates that the condition is contributing maximum up to 38%, speed is contributing up to 9 % whereas Depth of penetration and feed have least contribution in surface roughened steel*.

Keywords surface roughness ,burnishing, steel

SURFACE FINISHING PROCESS

Machining operations are used to produce the desired shape and size by removing excess stock from a blank in the form of chips. When the work piece is subjected to different manufacturing operations, intense mechanical stresses and localized heating get involved in the process thus create machining marks on the surface of the work piece. The work piece and tool in combination with the machine on which they mounted create a vibratory system responsible for random, forced or induced vibration. Because of these vibrations, the surface of the machined component gets less or more damaged in terms of surface finish and surface integrity. The degree of surface finish describes the geometry and microstructural quality of the machined surface.

1.2 SURFACE FINISHING PROCESSES

The different methods used for finishing the surfaces of the parts are discussed below:

Grinding
Lapping
Honing
Buffing
Barrel Rolling
Polishing
Super finishing
Burnishing

1.3 RANGES OF SURFACE FINISH OBTAINED BY VARIOUS SURFACE FINISH METHODS

Table 1.1Various surface finish methods and their finishing ranges

Process	**Average applications (µm)**
Grinding	0.1 to 1.6
Lapping	0.05 to 0.4
Honing	0.1 to 0.8
Buffing	0.05 to 0.5
Super finishing	0.05 to0.2
Burnishing	0.2 to 0.8

1.4 BURNISHING

Burnishing is a cold-working process in which plastic deformation occurs by means of applied pressure through a very hard and smooth metal ball or roller. Application of burnishing processes can improve surface finish, yield strength, fatigue resistance, wear resistance, surface hardness, tensile strength and corrosion resistance. As in this process, there is no removal of the extra material from the surface of a work piece, so burnishing is a chipless finishing process.

1.5 BURNISHING MECHANISM

Fig 1.1 shows burnishing mechanism in which a ball/roller of radius R is moving on the surface of machined specimen with a velocity V. As the ball/roller moves on the surface, due to elastic and plastic deformation, the hill is pushed into the valley. The surface roughness of the specimen before burnishing is R_o. As ball/roller moves on the surface of specimen, the $h_d$is the plastic deformation and the $e_r$is the elastic deformation.

Fig 1.1 shows

h_f= height of the valley through which it is filled up as the hill is pushed into the valley.

R_f= final surface roughness.

2L= the projected length of ball/roller that is in contact with surface asperities.

h = total deformation i.e. sum of elastic and plastic deformation.

So burnishing is a combination of elastic plastic deformation.

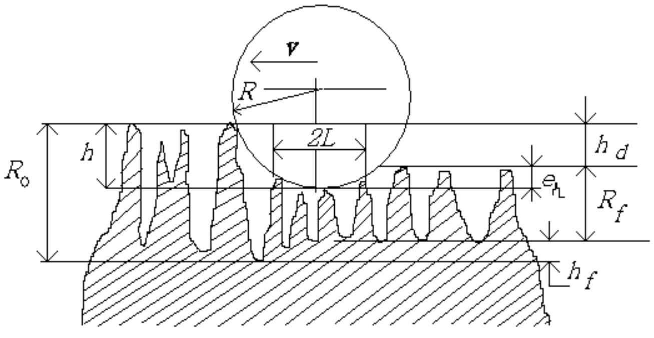


Figure 1.1 Burnishing Process

1.6 ROLE OF BURNISHING

However, in the recent years, attention has been paid to operations, which improve the surface characteristics, by plastic deformation. Such operations are sometimes referred as plastic surface deformation. Roller burnishing falls into this category and is becoming more widely employed. In this process, a very hard roller is used to move over the surface of the work piece. In the course of conventional machining process some geometric error like, out of roundness and cylindrical inaccuracies surface defects such as roughness, micro cracks, waviness surface burning, residual tensile stresses and plastic creep which make the component unfit for precision applications. Poor surface furnish will lead to the rupture of oil films on the peaks of micro irregularities that result in dry friction and excessive wear of surface in contact. Some functional and tribological properties like fatigue strength, corrosion, wear resistance and friction are dependent on surface finish and surface texture.

To minimize the above listed imperfections, burnishing process is used to smooth the surface by decreasing the peak to valley height. Its other use is that it decreases the residual tensile stresses and macro irregularities by filling up cracks. Further, it hardens the surface and toughens the skin to make it more wear resistant.

1.7 TYPES OF BURNISHING

This process is classified as follows.

(i) Ballizing Processes
(ii) Roller Burnishing
(iii) Ball Burnishing

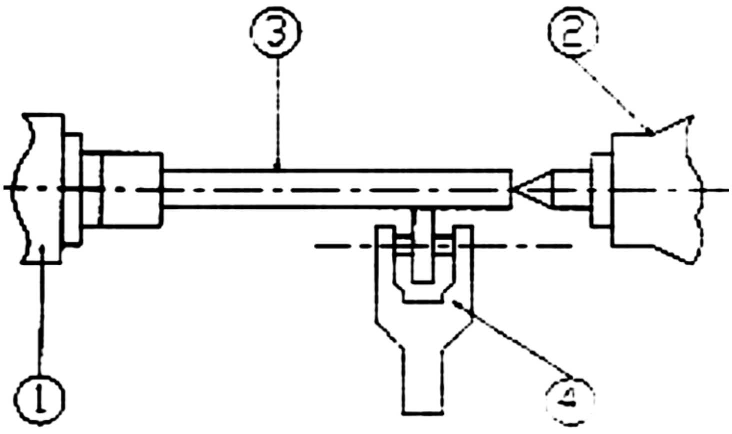
These processes are explained briefly as follows

(i) Ballizing Process

In this process push rod is used to force a ground hard ball of a prescribed diameter through a slightly undersized pre machined hole. There is practically no rotation in this process. Unlike conventional ball, burnishing tools where the tool or work piece must be rotated. The axis of the ball remains in motion and conforms closely to the axis of the hole, as there is no physical connection between the ball and the push rod.

(ii) Roller Burnishing

Roller burnishing is mostly used for cylindrical surfaces, flat surfaces or to burnish large inner diameters. Here a hard roller is employed to improve surface specifications such as hardness, surface finishing and wear resistance of the mechanical components. Roller burnishing operation is shown in Fig. 1.2.

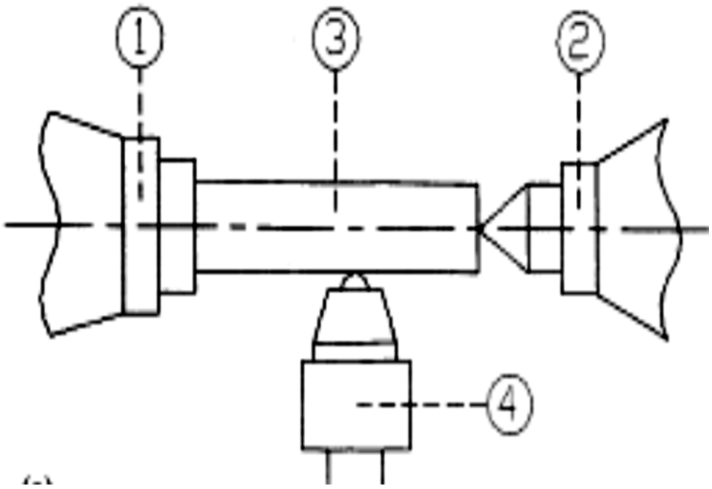


1Head stock 2 Tail stock 3 Job 4 Roller burnishing tool

Figure 1.2 Roller Burnishing

(iii) Ball Burnishing

In ball burnishing process hard ball penetrates up to the prescribed depth to the pre machined surface. Work piece and burnishing tool move in certain specified direction, i.e. in the opposite direction or one is moving and the other remains stationary. The surface finish obtained after burnishing depends on the depth of penetration, speed and lubricant used if any. Experimental setup of ball burnishing is shown in Fig. 1.3.



1 Head stock 2 Tail stock 3 Job 4 Ball burnishing tool
Figure 1.3 Ball Burnishing

1.8 CLASSIFICATION ACCORDING TO THE SURFACE TO BE BURNISHED:

Burnishing may be classified according to the surface to be burnished as follows

(i) External Burnishing
(ii) Internal Burnishing
(iii) Burnishing of Flat Surfaces
(iv) Thread Burnishing

Different type of burnishing is explained in brief as below

(i) **External Burnishing:**

External burnishing is used for finishing of external cylindrical surfaces. In this process, the work piece is held between two centers of a lathe machine. The roller-burnishing tool is pressed on rotating cylindrical surface of the work piece. A feed is given to the tool along the axis of the job as shown in Fig 1.4.

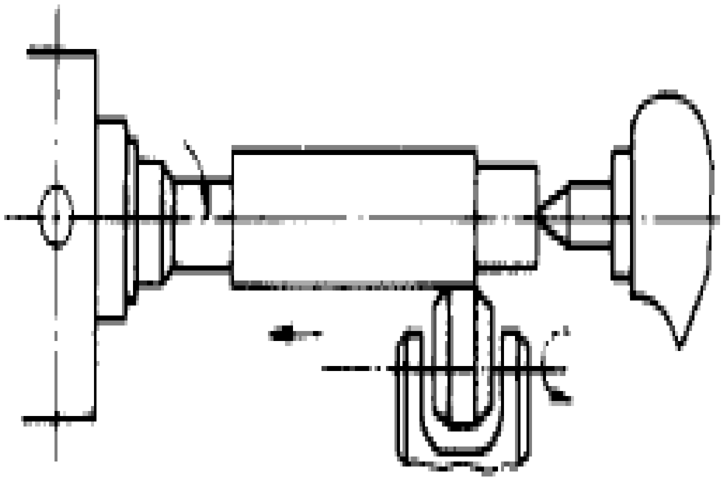


Figure 1.4 External Burnishing

(ii) **Internal Burnishing:**

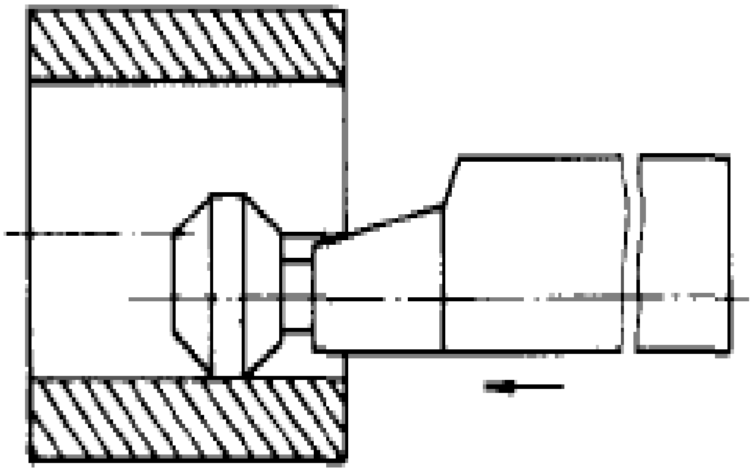


Figure 1.5 Internal Burnishing

Internal burnishing is used to burnish the internal surfaces with a ball/roller pressed through sleeve shown in Figure 1.5. The Roller of the tool is such designed that it can enter easily in the job for burnishing.

(iii) **Burnishing of Flat Surfaces:**

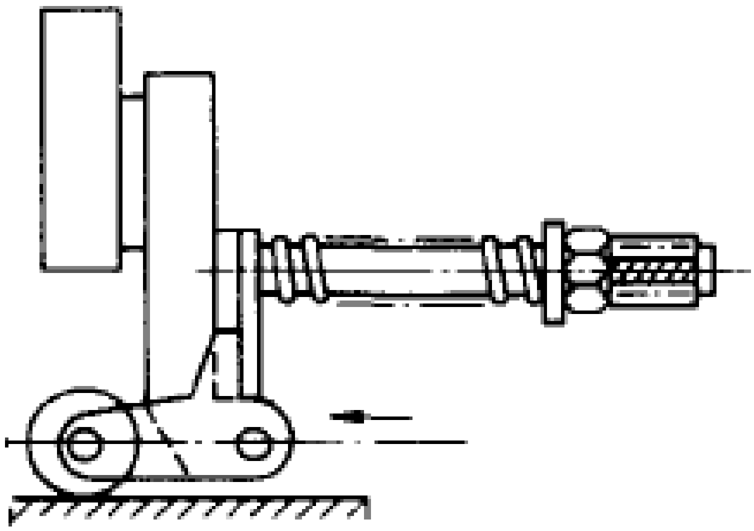


Figure 1.6 Burnishing of Flat Surfaces

In the burnishing of flat surfaces, the roller of the burnishing tool moves on the surface of stationary job as shown in Figure 1.6.

(iv) **Burnishing of Curved Surfaces:**

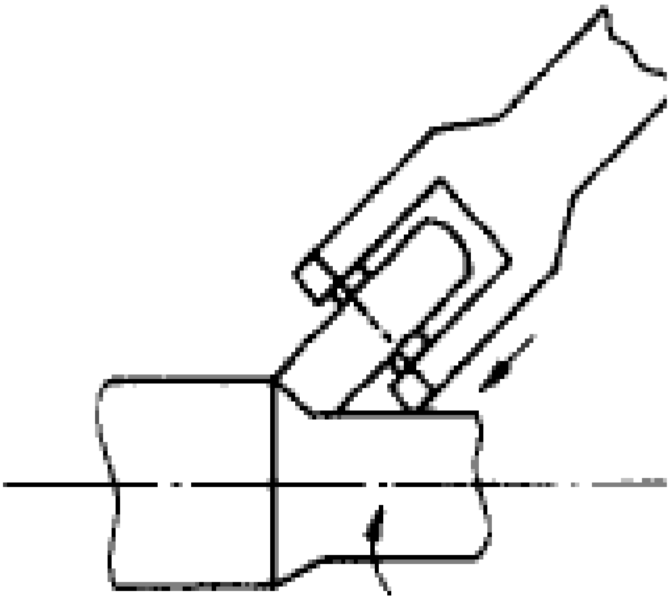


Figure 1.7 Burnishing of Curved Surfaces

In burnishing of curved surfaces tool is designed in such a way that it can move along the profile of the surface. Fig 1.7 shows an example of curved surfaces burnishing.

1.9 SHAPES OF ROLLERS USED IN BURNISHING PROCESS

Different types of roller are used in roller burnishing process. Roller used in the process should have high surface finish and high hardness. Commonly used rollers in burnishing are shown in Fig 1.8.

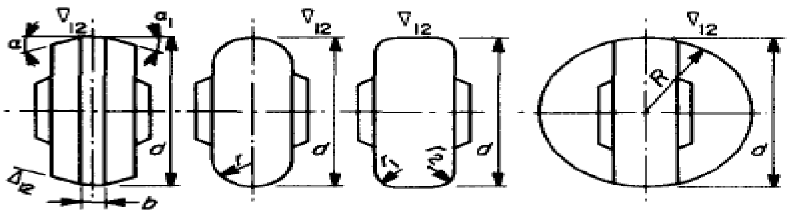


Figure 1.8 Different Types of Roller

1.10 BURNISHING TERMINOLOGY

The following terminology is used in the burnishing process as shown in Fig. 1.9.

1. **Burnishing Speed:** The speed at which work piece is rotating is known as Burnishing Speed. It is measured in rpm.
2. **Burnishing Feed:** The speed at which the tool is moving along the axis of work piece is known as Burnishing Feed. It is measured in mm/revolution.
3. **Burnishing Force:** The Force exerted by tool on work piece surface is known as Burnishing Force. It is taken in kgf.
4. **Depth of Penetration:** The depth up to which tool penetrate in pre-machined surface is called Depth of Penetration. It is measured in µm.
5. **Burnishing Direction:** The direction towards which the tool moves on the work piece surface.
6. **Surface roughness:** Surface roughness represents the average departure of the surface from perfection over a prescribed sampling length. It is measured in µm.

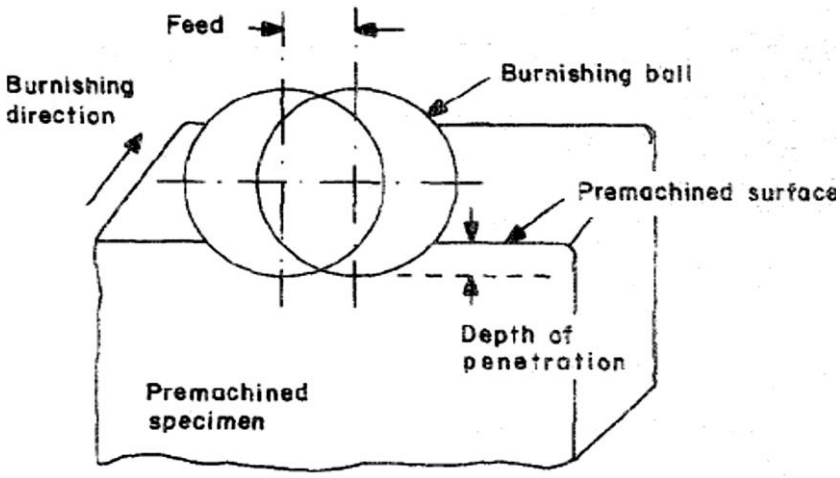


Figure 1.9 Illustrations of terminology

1.11 FACTOR AFFECTING SURFACE FINISH DURING BURNISHING

1. **Burnishing Force:** As burnishing force between tool and specimen increase the surface finish increases up to an extension after that cutting of material starts.
2. **Burnishing Speed:** Surface finish increases with burnishing speed of job.
3. **Burnishing Feed:** Surface finish increases with burnishing feed, but up to a limit point.
4. **Lubricant:** With the use of lubricant during burnishing the surface finish increases.
5. **Number of Passes:** Surface finish increases with no. of passes, but after some definite passes it becomes constant.
6. **Hardness of Tool:** As the hardness of tool increases the surface finish produced increases.
7. **Surface Condition of Tool:** If tool surface is rough it will produce rough surface. If it is finished so it will produce finished surface. So surface finish is directly proportional to the surface finish of the tool.
8. **Initial Condition of Surface to be burnished:** If the surface is rougher, the percentage of improvement in surface finish will be more.

1.12 ADVANTAGES OF BURNISHING

1. Good surface finish like honing and lapping can be produced with burnishing. Also, this process is a combination of high surface finish and accuracy.
2. Burnishing requires very less time as compared to another surface finish process as honing and lapping and gives same surface finish.
3. Along with the surface finish other properties also improves such as hardness and fatigue strength, etc.
4. Simplicity and stability of the process characteristics, thus makes it suitable for automation.

1.13 APPLICATIONS OF BURNISHING

Industrial useful application of burnishing are machine tool and metal forming, instrumentation, nozzles of carburetor jets, fluid logic controls, aerospace industries, automotive industry. Roller burnishing has been used in industry since a long time using standard as well as special tooling. Some typical applications are finishing internal diameters of short holes, taper seats for line contact and better wear resistance, internal diameters and external diameters of hydraulic cylinders, face seals, spherical seats internal and external recesses, grease pit lifts, hydraulic elevator cylinders, pistons for hydraulic cylinders external diameter of bearing surfaces of crank shafts.

2 Objective of study

To investigate the effect of burnishing process parameters of 20MnCr5and to optimize the burnishing process parameters in order to reduce the surface roughness.

3 WORKPIECE MATERIAL

For the present study 20mncr5 steel is selected as work piece material having a diameter 40 mm and length of 300 mm. The chemical composition of 20MnCr5 steel is shown in Table 3.2

Table 3.2 Chemical Composition (in weight %)

Grade	Chemical composition (WT %)					
	C	**Mn**	**Si**	**P**	**S**	**Cr**
20MnCr5	0.17- 0.22	1.10--1.50	≤0.25	≤0.030	0.010-0.035	1.00- 1.30

3.4 BURNISHING TOOL

The burnishing tool selected for the present investigation is single roller burnisher which is available from the market. The roller of the burnishing tool is of carbide as shown in figure.

Figure 3.1 Burnishing tool from Bright burnishing tools Pvt. Ltd., Coimbotore

Table 3.3 Tool Specifications

Part Name	Specifications
Shank Dimensions	25 mm× 25mm
Shank Length	100 mm
Roller Material	Carbide
Roller Diameter	48 mm
Roller Width	30 mm

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4 The Influence of Surface Roughness

The surface roughness of a material plays a crucial role in the effectiveness of the burnishing process. High surface roughness can impede the uniform application of compressive forces, leading to inconsistent results and potential surface defects. Conversely, materials with a smoother initial surface may be more responsive to the burnishing process, resulting in more consistent and desirable outcomes (Wardhana et al., 2019).

Research has shown that the feed, cutting speed, tool material, and workpiece material are all important factors that can affect the surface roughness of a machined surface (Escalona & Maropoulos, 2009). In particular, the study by Bouzakis et al. found that using low cutting speeds and feed rates can lead to higher surface roughness values, which may in turn impact the effectiveness of subsequent burnishing operations. (Escalona & Maropoulos, 2009)

4.1The Role of Cutting Parameters

In addition to the initial surface roughness, the cutting parameters used during the machining process can also significantly influence the success of the burnishing operation. Factors such as tool wear can lead to increased surface roughness, which may diminish the benefits of the burnishing process. Conversely, optimizing the cutting parameters can result in a smoother initial surface, potentially enhancing the effectiveness of the burnishing process. One study by Kumar et al. examined the effects of cutting speed and gas pressure on the surface quality of laser-cut 316L stainless steel. The results showed that changes in cutting speed had a more significant impact on surface roughness, while gas pressure had a greater influence on surface hardness.

4.2 The Effect of Burnishing on Surface Characteristics

The application of the burnishing process can lead to significant improvements in the surface characteristics of a material, such as increased hardness, improved wear resistance, and enhanced fatigue life. These improvements are largely attributable to the compressive forces applied during the burnishing process, which can induce beneficial residual stresses and microstructural changes in the surface layer. However, the effectiveness of the burnishing process is strongly dependent on the initial surface roughness of the material, as well as the cutting parameters used during the machining process.

5 RESULTS AND DISCUSSION

SURFACE ROUGHNESS (SR)

Code given on specimen	Condition	Speed	Feed	Depth of Penetration	Number of Passes	Ra (µm)			Mean (µm)
						Trail I	Trial II	Trail III	
A	WET	100	0.5	0.1	1	0.640	0.695	0.689	0.67
B	WET	100	1.0	0.2	2	0.352	0.315	0.480	0.38
C	WET	100	1.5	0.3	3	0.203	0.148	0.289	0.21
D	WET	150	0.5	0.1	2	0.129	0.132	0.140	0.13
E	WET	150	1.0	0.2	3	0.225	0.289	0.209	0.24
F	WET	150	1.5	0.3	1	0.397	0.425	0.392	0.40
G	WET	200	0.5	0.2	1	0.245	0.259	0.308	0.27

H	WET	200	1.0	0.3	2	0.600	0.589	0.650	0.61
I	WET	200	1.5	0.1	3	0.653	0.798	0.841	0.76
J	DRY	100	0.5	0.3	3	1.089	1.473	1.814	1.46
K	DRY	100	1.0	0.1	1	0.890	0.890	0.890	0.89
L	DRY	100	1.5	0.2	2	0.528	0.700	0.596	0.61
M	DRY	150	0.5	0.2	3	0.487	0.385	0.697	0.52
N	DRY	150	1.0	0.3	1	0.839	1.089	0.795	0.91
O	DRY	150	1.5	0.1	2	0.598	0.684	0.652	0.64
P	DRY	200	0.5	0.3	2	0.489	0.389	0.632	0.50
Q	DRY	200	1.0	0.1	3	0.689	0.689	0.799	0.73
R	DRY	200	1.5	0.2	1	0.451	0.589	0.696	0.58

Table 5.1 Experimental results for SR are tabulated in

Table 5.1Experimental results for surface roughness

The results for surface roughness (SR) are analyzed using ANOVA in Minitab 17 software. As lower value of surface roughness is the requirement in experimentation so the criterion for evaluation "smaller is better" is used. Table 5.2 summarizes the information of analysis of variance and case statistics for further interpretation.

Table 5.2 Analysis of Variance for means of SN ratio for SR (Smaller is Better)

Source	**DF**	**SEQ SS**	**Adj Ss**	**Adj Ms**	**F**	**P**	**Percentage Contribution**
Condition	1	167.97	167.97	167.972	5.95	0.135	38
Speed	2	40.08	40.08	20.038	0.71	0.585	9
Feed	2	10.24	70.23	35.116	1.24	0.446	2
Depth of Penetration	2	31.69	31.69	15.843	0.56	0.64	7
Number of Passes	2	38.94	38.94	19.971	0.35	0.739	9
Condition*Speed	2	49.75	49.75	24.873	0.88	0.532	11
Condition*Depth of Penetration	2	16.87	51.13	25.565	0.91	0.525	4
Condition*Number of Passes	2	52.16	52.16	26.081	0.92	0.52	12
Residual Error	2	36.45	36.45	18.224			8
Total	17	445.14					100

ANOVA table for surface roughness clearly indicates that the burnishing feed and depth of penetration are relatively less influencing factors for SR and burnishing condition, burnishing speed and numbers of passes are the most influencing factors for SR. Interaction between burnishing condition and burnishing speed, burnishing condition and numbers of passes are also influencing SR.

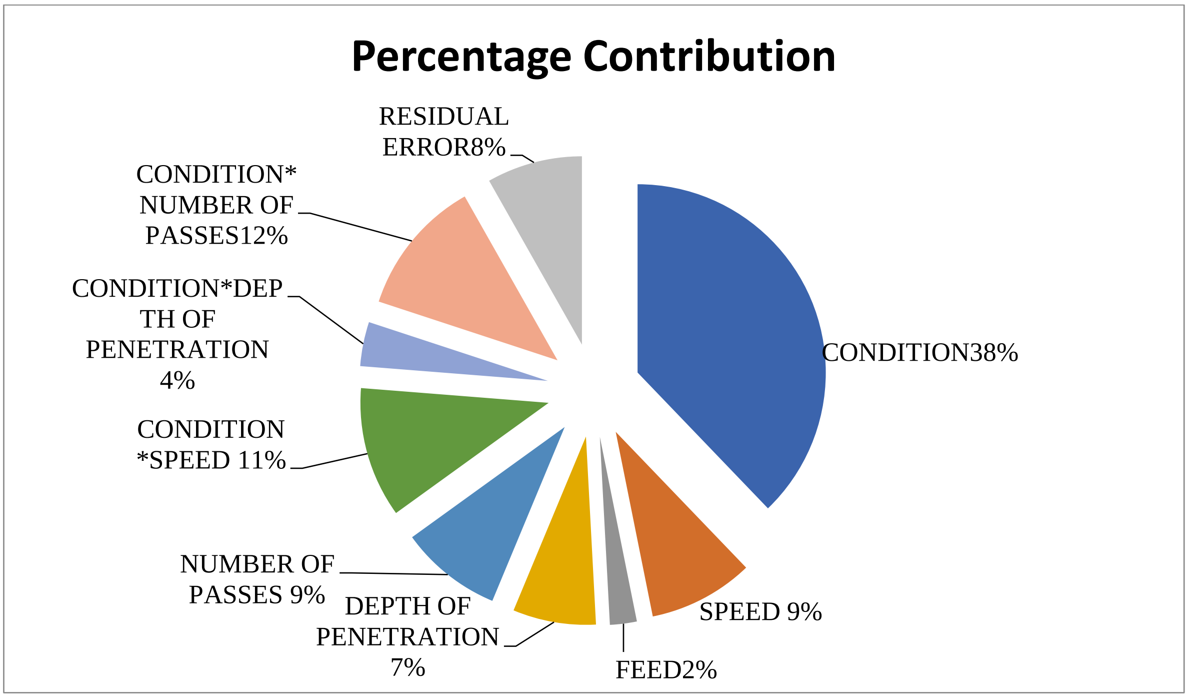

Figure 5.1 Percentage contributions towards surface roughness

From the percentage contribution pie chart it is concluded that the condition is contributing maximum up to 38%, Speed is contributing up to 9 % whereas Depth of penetration and feed has least contribution in surface roughness of 20MnCr5 steel.

During the burnishing process the effect of different parameters like condition, speed, feed, Depth of penetration and number of passes on surface roughness in terms of SN ratio is shown in Figure 5.2.

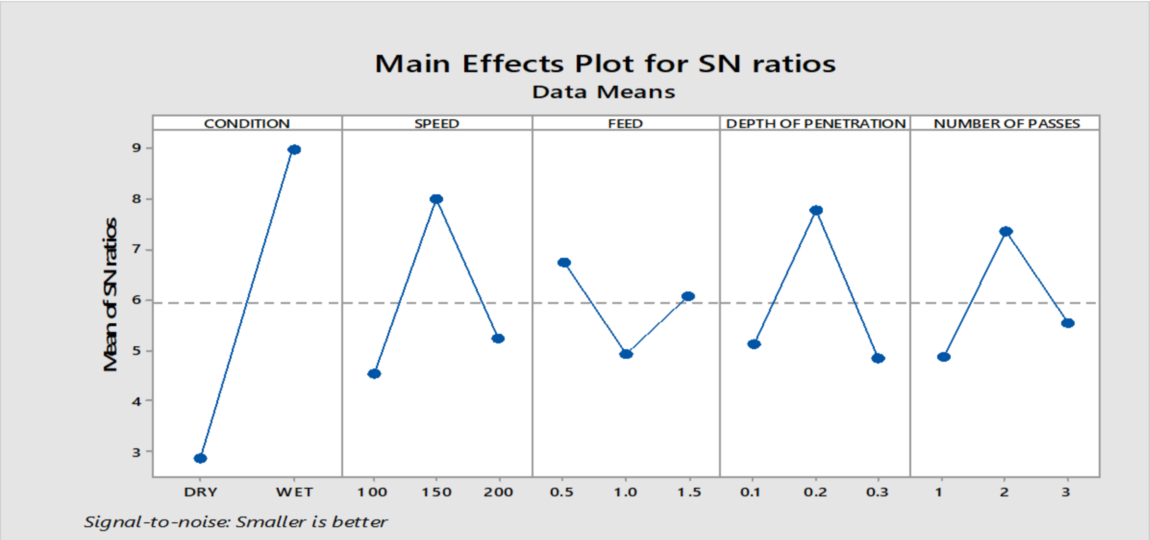

Figure 5.2 Main effects plot for means SN ratios (Surface Roughness)

It is clear from Figure 5.2 that surface roughness is minimum at the 1st level condition, 2nd level of speed, 1st level of feed, 2nd level of depth of penetration and 2nd level of number of passes. Main effect plots for SN ratios suggest these levels of the parameters as best levels for minimum SR as shown in table 5.3.

Table 5.3 Levels of input parameters at minimum SR

Factor	Condition	Speed	Feed	Depth of penetration	Number of passes
Level	1	2	1	2	2

From the ANOVA table it is found that the interaction between no. of passes, feed, speed and depth of penetration, condition is significant towards surface roughness.

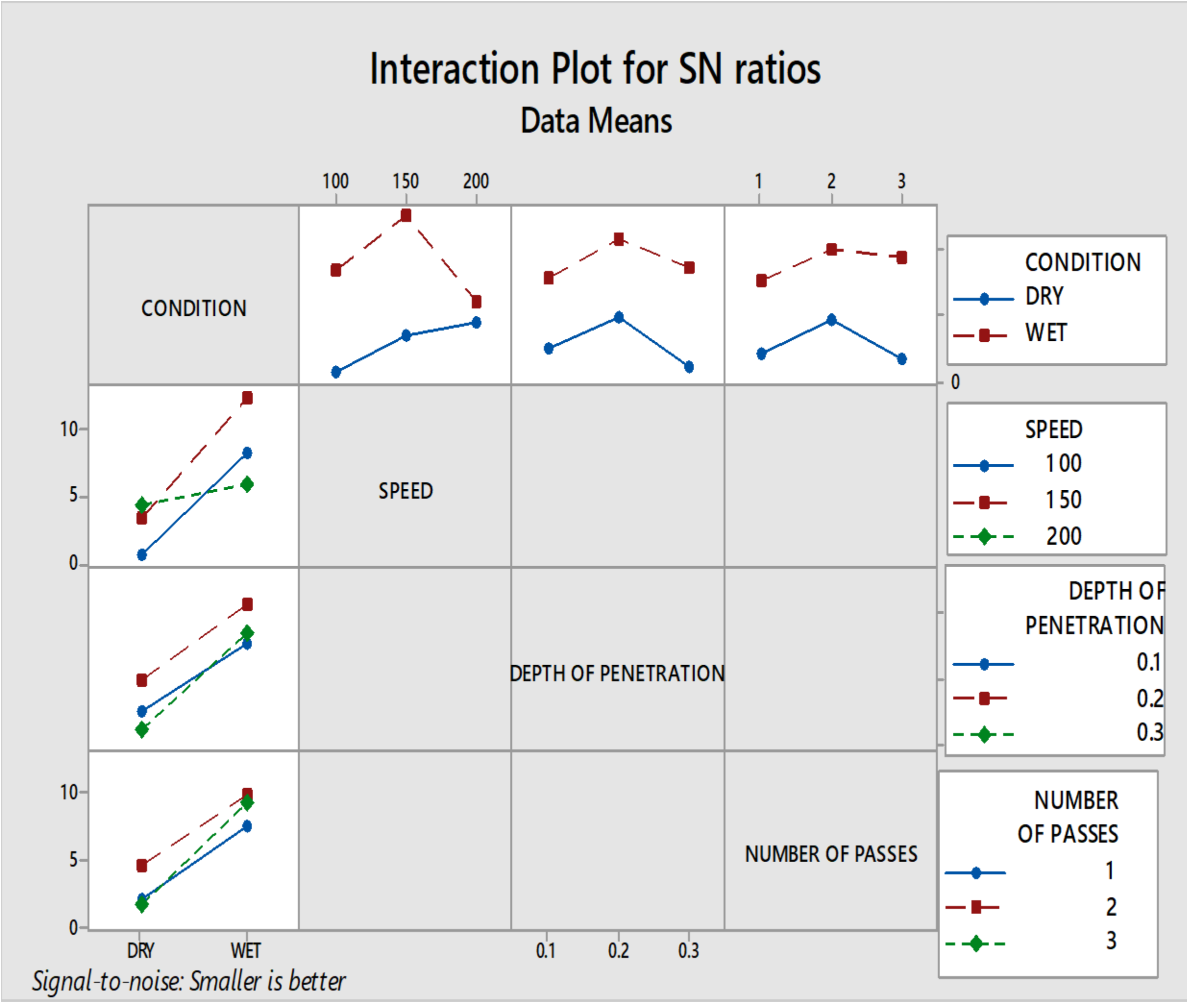

Figure 5.3 Interaction Plot for SN Ratios (Smaller the better)

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