IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Experimental investigation on machinability of 15-5PH stainless steel at different level hardness using TiAlN coated carbide tool

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ABSTRACT

This study is to investigate the effect of heat treatment and process parameter's on different machinability aspect like surface roughness and cutting forces during turning of 15-5PH stainless steel at various conditions. After heat treatment process the mechanical properties, microhardness. Maximum hardness (465 HV) was obtained after heat treatment in the H900 condition and air cooled and minimum hardness (293 HV) was obtained at condition H1150M furnace cooled. Higher machining rates are found to be possible with conditions H1150 and H1150M. In all cases surface roughness and cutting force have been measured. From the experimental results it has been observed that at minimum feed rate and maximum cutting speed the cutting force and surface roughness were minimum.

Keywords: CNC turning; Heat treatment; Mechanical properties; Cutting force; Surface roughness,; 15-5PH stainless steel.

I. INTRODUCTION

Precipitation hardening stainless steels are chromium and nickel containing steels that provide an optimum combination of the properties of martensitic and austenitic grades. Like martensitic grades, they are known for their ability to gain high strength through heat treatment and they also have the corrosion resistance of austenitic stainless steel. Precipitation-hardening (15-5) stainless steels provide an outstanding combination of high strength, good corrosion resistance, good mechanical properties and good toughness. When good fracture toughness or impact toughness is required, both at and below room temperature, heat treatment conditions H900 and H925 should be used. The H1150M condition results best notch toughness and is recommended for cryogenic applications [1,21]. By various heat treatment methods, it is desirable to improve the hardness and mechanical properties and achieve good machinability which will expand the application range of precipitation hardened stainless steel. That is way they are used in aircraft, aerospace and nuclear industries [9]. In addition, it is more cost effective than many high-nickel, non-ferrous alloys. In precipitation hardening stainless steel tensile and yield strength can be achieved by a low temperature (about 900°F) aging treatment in combination with cold working. Precipitation hardenable (PH) stainless steels are chromium-nickel grades that can be hardened by an aging treatment [2]. TiAlN coated tools is appropriate for the higher speeds and feeds used in machining operations involving turning, milling and drilling, as well as die casting or hot forging applications. The popularity of TiAlN-based coatings is based on lowering of operating costs by eliminating coolants, disposal, chip cleaning and part washing. As a result, they can improve the productivity in typical machining applications by as much as 40%. [16]. TiAlN coating has good thermal stability and withstands at high temperature especially in turning and helps to reduced cutting forces [10].

While turning 35 and 45 HRC work material by TiAlN coated tools, minimum cutting forces, surface roughness is observed at low feed, low depth of cut and by limiting the cutting speed between 140m/min and 225 m/min [12, 20].

Abbreviations	
V_c	Cutting speed
f	Feed rate
D	Depth of cut
F_Z	Cutting force
Ra	Surface roughness
HV	Vickers hardness
AS	Condition ‘ A’ solution treated
AC	Air cooled
FC	Furnace cooled

II. EXPERIMENTAL DETAILS

2.1 Workpiece material

The material employed to this work is 15-5PH stainless steel. The name comes from the additions 15% Chromium and 5% Nickel and is also known by its Unified Numbering System (UNS) designation of S15500.Production of 15-5 PH stainless steel begins with casting and then extruded in the form of round bar having length of 120 mm and diameter of 32 mm. The Chemical composition of 15-5 PH stainless steel was shown in table 1. The alloy is subsequently annealed to refine the grain shapes and sizes and is delivered in this condition, referred to as “condition A”.

Table 1 CHEMICAL COMPOSITION OF 15-5PH STAINLESS STEEL BY WEIGHT PERCENTAGE

Element	Fe	C Max.	Cr	Ni	Cu	Mn Max.	Nb+Ta	S Max.	Si Max.	P Max.
Weight (%)	Bal	0.07	14.00-15.50	3.50-5.50	2.50-4.50	1.0	0.15-0.45	0.03	1.0	0.04

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ISSN (O) 2319 - 8354
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2.2 Heat treatment

15-5PH stainless steel is supplied from the mill in Condition A and is heat treated at a variety of temperatures to develop a wide range of properties. The heat treatment has been conducted with the help of electrical furnace. The heat treatment conditions were shown in table 2

Table 2 HEAT TREATMENT PROCEDURE

Condition 'A' Solution Treated	1038 ± 14 ˚C/min	30 min	Air cool/Oil cool below 32 ˚C
H900	482 ± 6 ˚C	1	Air
H900	482 ± 6 ˚C	1	Furnace
H1150M (double overage)	760 ± 6 ˚C followed by 621 ± 6 ˚C	2 followed by 4	Air
H1150M (double overage)	760 ± 6 ˚C followed by 621 ± 6 ˚C	2 followed by 4	Furnace

2.3 Measurement

15-5PH stainless steel is heat treated at a variety of temperatures to develop a wide range of properties. After heat treatment tensile testing were carried out with the help of Universal Testing Machine to find out the mechanical properties and for hardness the test were performed on Vickers hardness tester machine. The surface charecteristic of machined surface can be measured by parameter like Rz- peak value or Ra- average value using Mitutoyo surface roughness tester. Mounting of tool dynamometer allows direct measurement of turning forces to which it is subjected. The tool to be examined is mounted on the cover plate of the dynamometer. The dynamometer measures the reaction forces on the rotating work peace via the tool. The cutting force was measured using a Kistler piezoelectric dynamometer.

2.4 Experimental set-up and procedure Turning test were conducted with TiAlN coated carbide tool insert with an ISO designation CNMG 120408 was used. TiAlN-based coatings, typically deposited as 2–5 µm thick films with hardness ranging between 3000 and 3300 HV, are thermally stabile between 800 and 900 ºC and have the coefficient of friction between 0.35 and 0.4. The inserts were mounted on a tool holder with an ISO designation PCLNL 1616 H12. Test was carried out on LEADWELL CNC turning center shown in fig. 1

Fig.1 Turning operation on CNC lathe

There is some agreement in the literature regarding the surface roughness and forces with each cutting parameters (cutting speed, feed, and depth of cut). In this work, machinability of 15-5PH stainless steel has been

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

studied with respect to surface integrity and force in different set of cutting parameters. The parameter and their levels were shown in table 3 [9]

Table 3 PARAMETER AND THEIR LEVELS

Parameter's	Level 1	Level 2	Level 3
Cutting speed V_c (m/min)	125	175	225
Feed f (mm/rev)	0.06	0.12	0.18
Depth of cut d (mm)	0.5	0.5	0.5

III. RESULT AND DISCUSSION

3.1 Mechanical properties

After heat treatment tensile testing were carried out to find out the mechanical properties and characteristics. The various kinds of mechanical properties was shown in table 4

Table 4 MECHANICAL PROPERTIES

15-5PH stainless steel	Condition A Solution treated	H900 (Air cooled)	H900 (Furnace cooled)	H1150M (Air cooled)	H1150M (Furnace cooled)
Hardness (Hv0.5)	354	468	437	325	293
Maximum force (KN)	30.325	42.654	38.479	27.548	24.175
Tensile Strength (GPa)	1.336	1.562	1.412	1.011	0.958
Elongation (%)	14.520	13.468	11.324	15.013	15.615
Reduction in Area (%)	63.386	52.306	58.785	65.190	66.132

3.2 Experimental cutting parameters and corresponding response value

The experimental results of machining were shown in table 5

Table.5 EXPERIMENTAL RESULTS OF MACHINING OF 15-5PH STAINLESS STEEL AT DIFFERENT CONDITIONS

Exp. No	Cutting speed V_C (m/min)	Feed rate f (mm/rev)	Depth of cut d (mm)	H900 Air Cooled		H900 Furnace Cooled		Condition' A' solution treated		H1150M Air Cooled		H1150M Furnace Cooled	
				Fz (N)	Ra (µm)	Fz (N)	Ra (µm)	Fz (N)	Ra (µm)	Fz (N)	Ra (µm)	(Fz) N	Ra (µm)
1	125	0.06	0.5	104.13	0.502	102.8	0.913	83.13	0.76	76.29	0.391	67.39	0.489
2	125	0.12	0.5	106.32	1.158	105.96	0.999	96.68	1.255	94.24	1.204	94.84	0.942
3	125	0.18	0.5	135.74	1.185	126.34	1.279	125.37	1.507	121.83	1.539	123.41	1.038
4	175	0.06	0.5	92.41	0.384	91.9	0.714	80.57	0.354	62.87	0.371	58.60	0.424
5	175	0.12	0.5	93.26	0.983	92.16	0.965	86.18	1.286	84.11	1.106	87.16	0.800
6	175	0.18	0.5	115.36	1.103	115.48	1.261	108.03	1.437	106.69	1.297	105.23	1.011
7	225	0.06	0.5	61.4	0.233	63.6	0.255	59.5	0.342	53.47	0.303	54.68	0.202
8	225	0.12	0.5	87.89	0.755	86.67	0.692	85.08	0.768	84.23	0.523	77.27	0.346
9	225	0.18	0.5	112.92	0.952	110.23	0.886	107.54	1.239	105.83	1.05	100.83	0.729

3.4 Surface Roughness

Surface quality of the machined workpiece surface is dependent on mainly cutting conditions used. Fig. 2 (a), (b), (c) and fig. 3 (a), (b) and (c) were shows the graphical representation of surface roughness against the feed and cutting speed respectively for a constant depth of cut 0.5mm. It can be seen that the roughness value of the machined surface increases with the increase in feed. This is because of increase in feed leads to produce feed marks on the turned surface resulting in the increase in the roughness value. The surface roughness (Ra) was observed to be decreased with increased in cutting speed and also can be seen that it is low at high cutting speed because at higher cutting speed continuous chips without built-up edge was obtained which results in improvement of surface finish. Also, The TiAlN coated tool insert provide better thermal stability and chemical inertness at elevated temperature which prevents the formation of built- up edge. Minimum surface roughness (Ra) was obtained 0.202 µm at feed rate 0.06 mm/rev and cutting speed 225 m/min at H1150 furnace cooled condition.

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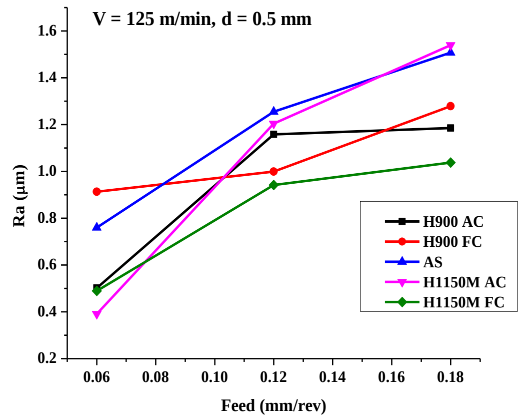
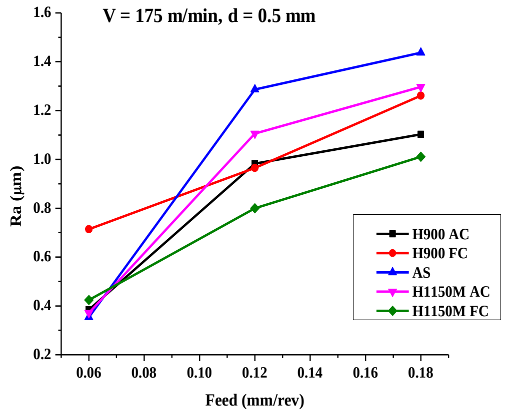
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346



(a)



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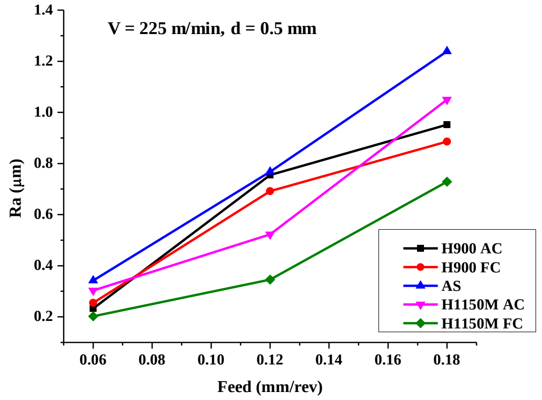

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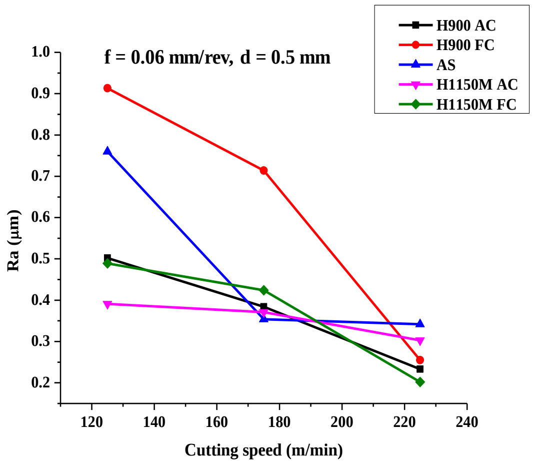
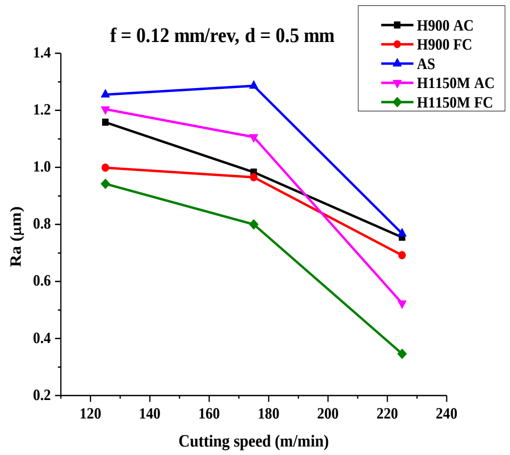
Fig. 2 (a), (b) and (c) shows the variation of Ra at different levels of feed rate

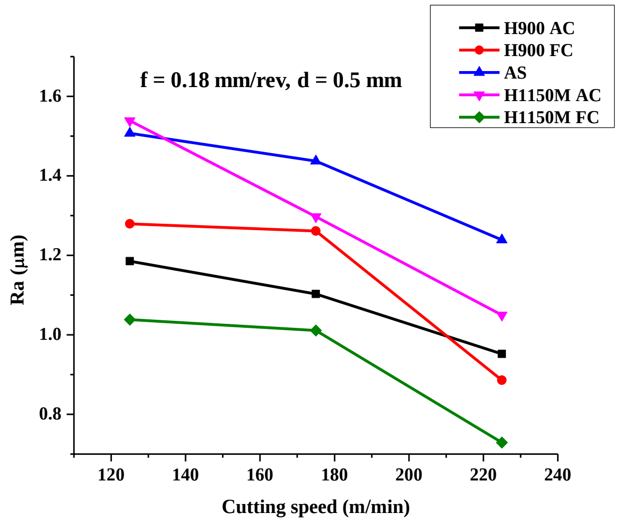


(a)



(b)

International Journal of Advance Research in Science and Engineering
Volume No 06, Special Issue No. (02), September 2017, ICITTESE-17
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346



(c)

Fig. 3 (a), (b) and (c) shows the variation of Ra at different levels of cutting speed.

3.5 Cutting Force

In turning operation three force components exists, that are cutting force, feed force and radial force. The cutting force acts along the direction of cutting speed (tangential to turned surface). This is major component of force. The feed force acts along the direction of the tool feed where as radial force acts perpendicular to the turned surface. Cutting force plays major role in determining the machinability hence, these are discussed. Fig. 4 (a), (b), (c) and fig. 5 (a), (b) and (c) were shows the graphical representation of cutting force against the feed and cutting speed respectively for a constant depth of cut 0.5mm. It can be seen that the cutting force increase with increase in feed rate because of the fact that with increase in feed shear plane area of the chip increases and forces required for cutting increases and also the tool wear and temperature in machining increases. It was observed that at low cutting speed, the forces were found to be higher because of the chip remains for long time in the rake face of the tool and which increases the tool-chip contact length. Therefore, it increases the friction between the tool and chip that resulted in higher forces. Similarly, while turning at higher cutting speed, the temperature generation rate is high which makes the material soft at cutting zone and helps in removing the material at lower cutting forces. Minimum cutting force was obtained 53.47 N at feed rate 0.06 mm/rev with cutting speed 225 m/min at condition H1150M air cooled

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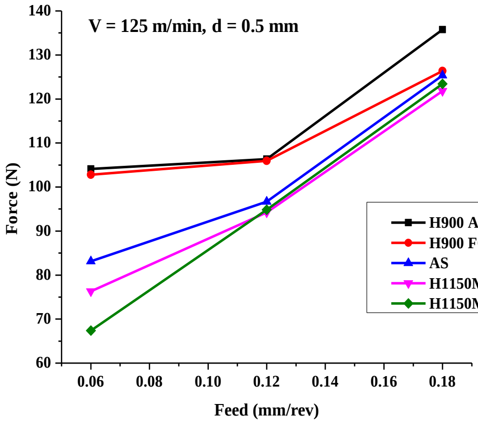
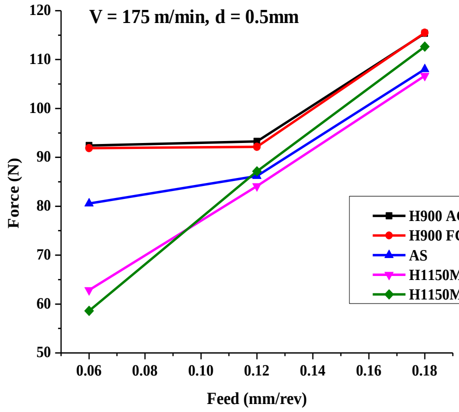
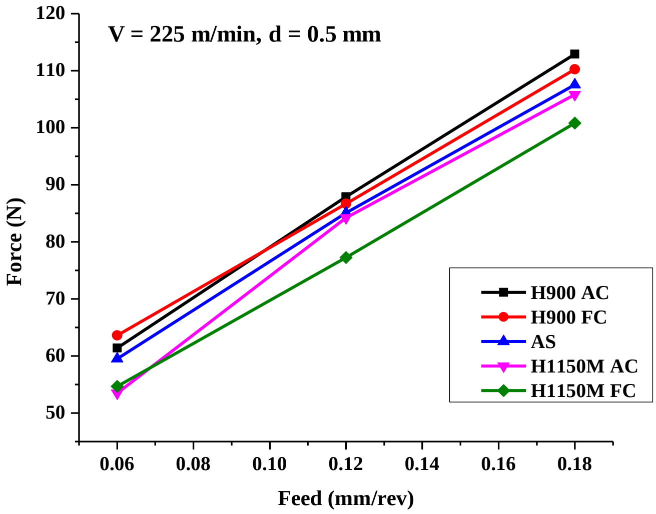
ISSN (P) 2319 - 8346





(a) (b)



(c)

Fig. 4 (a), (b) and (c) the variation of force at different levels of feed rate

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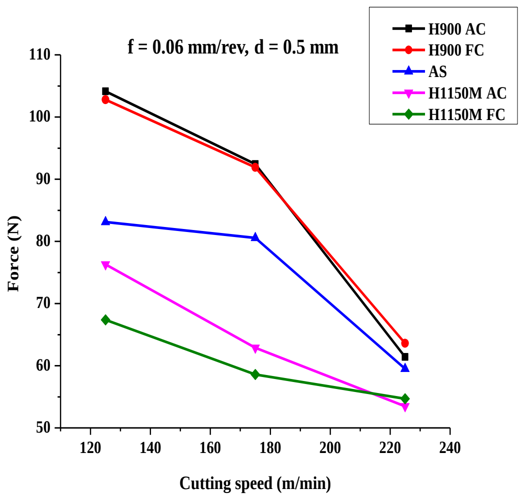
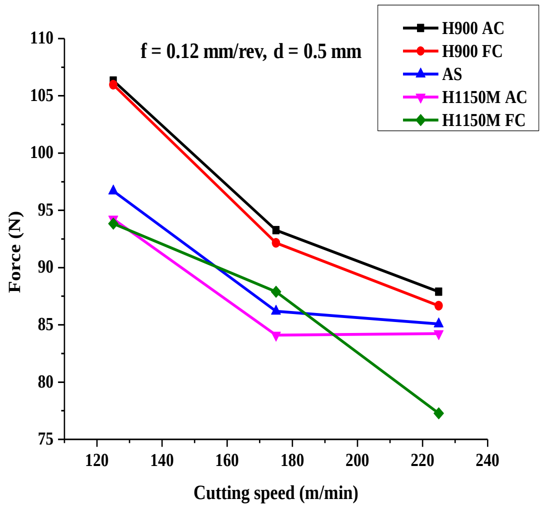
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346



(a)



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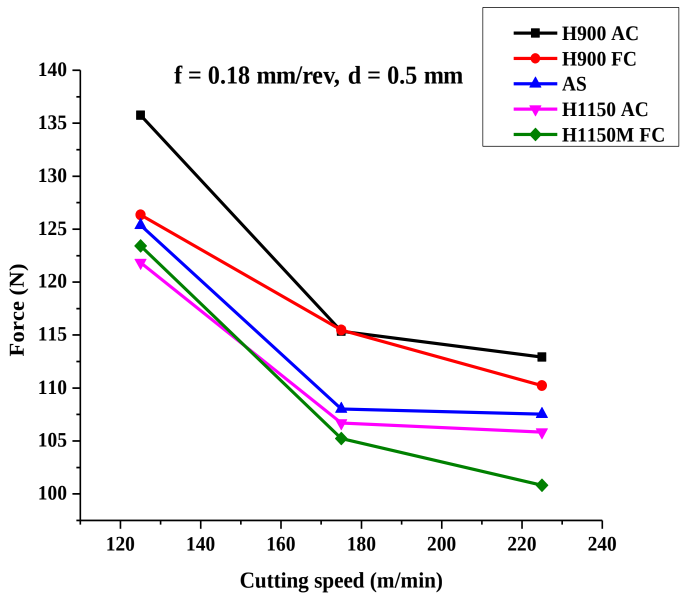

(c)

Fig. 5 (a), (b) and (c) the variation of force at different levels of cutting speed

IV. CONCLUASION

Experimental investigation on machinability of 15-5PH stainless steel has been performed. The mechanical properties after the heat treatment at various conditions have been determined. The effect of the cutting speed, feed and depth of cut on surface integrity and cutting force has been analyzed. The following conclusions are made from the results obtained.

- Maximum hardness (465 HV) was obtained after heat treatment in the H900 condition and air cooled and minimum hardness (293 HV) was obtained at condition H1150M furnace cooled.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

- The micro structures observed in as received and precipitation hardened condition is martensite. The precipitates formed during precipitation hardening or age hardening is submicroscopic particles, which are nanometers (nm) in size and are invisible under optical microscope.
- The cutting force increased with increase in feed and cutting forces decreased with the increase in cutting speed. Minimum cutting force was found (53.47 N) at feed rate 0.06 mm/rev with cutting speed 225 m/min at condition H1150M air cooled.
- With increase in feed rate surface roughness values increases where as it decreases with increase in cutting speed. Minimum surface roughness value was obtained 0.202 µm at feed 0.06 mm/rev with the cutting speed 225 m/min at condition H1150M air cooled (293 HV) and at H900 air cooled condition (465HV) for the same feed and cutting speed the value of surface roughness was 0.255 µm.

V. ACKNOWLEDGMENT

My deepest thanks to my guide Dr. T. Selvaraj, Professor, Department of Production engineering, National Institute of Technology, Tiruchirappalli for valuable support and guidance in making this project work success.

I sincerely express my gratitude to my Head of Department Dr. S Kumanan, Professor, Department of Production Engineering, National Institute of Technology, Tiruchirappalli for his co-operation and extending support.

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