Optimization of cutting parameters in CNC turning of stainless steel 304 with TiAlN nano coated carbide cutting tool

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Abstract. In this work, turning was performed to optimize the surface finish or roughness (Ra) of stainless steel 304 with uncoated and coated carbide tools under dry conditions. The carbide tools were coated with Titanium Aluminium Nitride (TiAlN) nano coating using Physical Vapour Deposition (PVD) method. The machining parameters, viz., cutting speed, depth of cut and feed rate which show major impact on Ra are considered during turning. The experiments are designed as per Taguchi orthogonal array and machining process is done accordingly. Then second-order regression equations have been developed on the basis of experimental results for Ra in terms of machining parameters used. Regarding the effect of machining parameters, an upward trend is observed in Ra with respect to feed rate, and as cutting speed increases the Ra value increased slightly due to chatter and vibrations. The adequacy of response variable (Ra) is tested by conducting additional experiments. The predicted Ra values are found to be a close match of their corresponding experimental values of uncoated and coated tools. The corresponding average % errors are found to be within the acceptable limits. Then the surface roughness equations of uncoated and coated tools are set as the objectives of optimization problem and are solved by using Differential Evolution (DE) algorithm. Also the tool lives of uncoated and coated tools are predicted by using Taylor’s tool life equation.

1. Introduction
Carbide cutting tool is a hard metal tool used in machining tough materials such as carbon steel or stainless steel. Carbide will leave a better finish on the part, allow faster machining and can withstand higher temperatures than standard high speed steel tools. Achieving the desired surface finish and controlling the chips during machining of a surface are dependent mainly on the geometry of the tool / insert. Also the performance of the cutting tool inserts improves with coating.

The results of longer tool life, higher cutting data and dry machining are possible only when the cutting tools are properly coated and designed. The important coatings available for carbide inserts are TiN (titanium nitride), TiC (titanium carbide), Ti(C)N (titanium carbide-nitride), and TiAlN (titanium aluminium nitride). In applications where heat is generated, TiAlN coatings are much more effective than TiCN coatings even though the former is not as much harder than the later at room temperature. A brief review of the literature on similar and related studies is presented here under.
Ghani et al [4] considered the machining of AISI H13 tool steel with TiN-coated carbide and uncoated cemented carbide tools, and investigated the wear mechanism at various combinations of cutting speed, feed rate, and depth of cut. Jeong Suk Kim et al [7] found that hard coatings of Ti–Al–Si–N improve the cutting performance of cutting tools in aggressive machining applications, such as high-speed machining. Abhiject et al [1] made a study on tool wear mechanism during turning of AISI 4340 hardened steel with CBN–TiN coated carbide inserts and PCBN compact inserts, and have proposed that PCBN is the dominant tool material for hard turning applications due to its high hardness, high wear resistance, and high thermal stability. Reginaldo, et al [12] analysed on tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions. Vikram Kumar et al [17] studied machining process under dry, wet and minimum fluid conditions of AISI 4340 hardened steel with TiCN and TiAlN coated tools, and compared their performance. Both the tools performed better with minimum fluid application when compared with dry and wet machining. Nur Akmal et al [9] made a study on the dry machining of Ti-6Al-4V using PVD coated TiAlN tools. Ibrahim Ciftci [6] conducted experimental study on CVD multi layer coated tools, viz., TiC/TiCN/TiN and TiCN/TiC/Al2O3 coated cemented carbide tools during dry turning of austenitic stainless steels (AISI 304 and AISI 316). They found out that the cutting speed significantly affects the machined surface roughness values. Chakraborty [2] prepared TiAlN/TiN multilayer coated carbide inserts using physical vapour deposition method, and made a study on tool life and flank wear when end milling of 4340 steel is done under dry and semi-dry cutting conditions. Harish et al [5] carried out a study on deposition and characterization of TiAlSiN nano composite coatings prepared by reactive pulsed direct current unbalanced magnetron sputtering.

Sergio and Federico [14] made a review of the fatigue behaviour of components coated with thin hard corrosion-resistant coatings such as the physically or chemically vapour deposited ones. Vikas Chawla [16] made a study on corrosion behaviour of nano structured TiAIN and AlCrN thin coatings on ASTM-SA213-T-11 boiler steel in simulated salt fog conditions. Nur Akmal [10] carried out a study on cutting performance of advanced multilayer coated (TiAIN/ AlCrN) in machining Of AISI D2 hardened steel. Ran Ji [11] developed CrAISIn nano multilayer coating system intended for high performance cutting conditions, and found that the new nano coating of CrAISIn possesses good resistance to rolling-sliding wear and attributed this to its improved toughness and oxidation resistance. Narasimha, et al, [8] investigated the machining performance of TiN, Al2O3/TiN/Al2O3, TiC/Al2O3/TiN and nano composite coated tungsten based cemented carbides during finish turning of AISI 1018 steel under dry conditions.

It is observed from the literature that, though there were number of studies on variety of coatings on cutting tools / inserts, there is less emphasis in literature on the effect of TiAlN coated cutting tools / inserts in turning process of stainless steel 304. Therefore, in the present work an attempt is made to study the effect of TiAlN coating as to how the performance of a Carbide cutting tool improves with regard to tool life and Surface Roughness under dry machining conditions.

2. Methodology
As the present study involves optimization of surface roughness of stainless steel 304 in turning operation, the surface roughness strategy has been developed for correlating the machining parameters (cutting speed, feed rate and depth of cut) with surface roughness using multiple regression technique. Actually two optimization problems with respect to the machining of coated and uncoated cutting tools are defined within the bounds identified under the experimental study by considering the
equations of surface roughness in terms of machining parameters as the objectives. Then the optimization of machining parameters is done using Differential Evolution (DE) algorithm. Finally confirmation tests were conducted to analyze the closeness of DE.

2.1 Mathematical formulation
The mathematical formulation involves the development of second-order regression equations for surface roughness in terms of machining parameters. The general response equation of second order polynomial is given by:

\[ Y_2 = Y - \varepsilon = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_1^2x_1^2 + b_2^2x_2^2 + b_3^2x_3^2 \]  

(1)

where \( Y_2 \) is the estimated second order response, \( Y \) is the measured response (surface roughness) on a logarithmic scale, \( \varepsilon \) is the experimental error, \( x_0 = 1, x_1, x_2 \) and \( x_3 \) are logarithmic transformations of variable parameters (cutting speed, feed rate and depth of cut respectively), and the values of \( b \) are the estimates of corresponding parameters. The method of least squares is to be used to estimate the parameters \( b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22} \) and \( b_{33} \).

3. Experimentation
The modelling and analysis of the influence of machining variables on the response variable is generally done by the design of experiments technique. In the present study, each variable parameter is set at three different levels within their machining ranges as shown in Table 1. All the interactions between the response variable and machining variables can be investigated by using an L\(_9\) orthogonal array of Taguchi method. Table 2 shows the design of machining parameters obtained by using L\(_9\) orthogonal array. In this work, stainless steel 304 work piece specimens of 80 mm length and 250 mm diameter were used. The density of stainless steel 304 is 8.03 gm/cc. The experiments were performed in dry conditions with coated and uncoated carbide tool. The chemical composition of stainless steel 304 (weight %) given by ASTM A 240 specifications is presented in Table 3. Table 4 shows the properties of TiAlN nano coating employed on the carbide cutting tool.

| Sample | Parameter          | Unit | Level-1 | Level-2 | Level-3 |
|--------|--------------------|------|---------|---------|---------|
| 1      | Cutting speed      | m/min| 140     | 180     | 224     |
| 2      | Feed rate          | mm/rev| 0.1   | 0.15    | 0.2     |
| 3      | Depth of cut       | Mm   | 0.5     | 1.0     | 1.5     |

Table 1. Machining variables used in the experimentation.

| Sample Number | Cutting speed (m/min) | Feed (mm/rev) | Depth of cut (mm) |
|---------------|----------------------|---------------|------------------|
| 1             | 140                  | 0.10          | 0.5              |
| 2             | 140                  | 0.15          | 1.0              |
| 3             | 140                  | 0.20          | 1.5              |
| 4             | 180                  | 0.10          | 1.5              |
| 5             | 180                  | 0.15          | 0.5              |
| 6             | 180                  | 0.20          | 1.0              |
| 7             | 224                  | 0.10          | 1.0              |
| 8             | 224                  | 0.15          | 1.5              |
| 9             | 224                  | 0.20          | 0.5              |

Table 2. Design of machining parameters using L\(_9\) orthogonal array.
Table 3. Chemical composition of stainless steel 304

|        | C%     | Mn%    | P%     | S% | Si%  | Cr%   | Ni%   | N%   | Fe%  |
|--------|--------|--------|--------|----|------|-------|-------|------|------|
| Max    | 0.08max| 2.00max| 0.045  | .030| 0.75 | 18.00-20.00| 8.00-12.00| 0.10max| Balance |

Table 4. Properties of TiAlN coating.

| Properties of Coating                                      | TiAlN               |
|-----------------------------------------------------------|---------------------|
| Micro hardness (HV 0.05)                                  | 3,300               |
| Friction coefficient (dry) against steel                  | 0.3 - 0.35          |
| Max. service temperature (°C)                             | 900                 |
| Coating colour                                            | violet-grey         |

Figure 1 shows the tool specifications considered in the present study. The carbide cutting tool used is an 80° tipped tool insert with a specification of CNMG 120408. Figure 2 shows the uncoated and coated cutting tools used in the experimentation. The TiAlN coating was employed through Physical Vapour Deposition process viz., Ion Plating method. PVD processing is carried out in high vacuum at temperatures between 150 and 500 °C. The high-purity, solid coating material (metals - Titanium, Aluminium) is evaporated by heat and bombardment of ions. At the same time, a reactive gas -nitrogen is introduced; it forms a compound with the metal vapour and is deposited on the tool as a thin, highly adherent coating. The CNC turning machine used in the present study is Hardinge SV 150 CNC turning centre (FANUC) with 25 KW drive power, 12 tool automatic changer and spindle speed range of 60-6,000 rpm.

In the present study, the surface roughness characterized by the statistical height descriptor (Ra), advocated by American National Standards Institute (ANSI) and International Standardization Organization (ISO) is used as the response parameter. The instrument used for measuring Ra was surface indicator. The device consists of a tracer head and amplifier. The tracer consists of a stylus which is moved on the surface of the work. The surface roughness was measured by using a portable surface roughness tester (Taylor Hobson surtronic 3+). Two measurements were taken on each machined surface and an average of the measurements is used as a response value. The accuracy of the tester is ±0.2μ. Figure 3 shows the measurement of surface roughness of a machined specimen using surface roughness tester.

3.1 Experimental Data

Figure 4 compares the surface roughness values of 9 sets of experiments with uncoated and coated carbide tool inserts. The minimum value of surface roughness is obtained at lower values of speed, feed and depth of cut for both uncoated and coated tool inserts. The surface roughness values of the coated carbide tool insert are better than the surface roughness values of uncoated carbide tool insert.
3.2 Variations of response parameter with respect to machining parameters

Figure 5 shows the effect of each turning process parameter (feed, depth of cut and spindle speed) of uncoated and coated carbide tool insert on surface roughness. Figure 5(a) shows the effect of feed rate at the selected levels of cutting speed on surface roughness without considering the depth of cut. It is observed from these graphs that for uncoated and coated tool, at all selected speeds, the graph shows an upward trend i.e., as feed rate increases the Ra value increases. Figure 5(b) shows the effect of cutting speed at the selected levels of feed rate on surface roughness without considering the depth of cut. It is observed from the graphs that for uncoated and coated tool, at all selected levels of feed rate, the graph shows an upward trend i.e., as feed increases, the Ra value increases slightly due to chatter and vibrations. Figure 5(c) shows the effect of feed at the selected levels of depth of cut without considering the cutting speed. It is observed from the plot that for uncoated and coated tools, at lower depth of cut, the graph shows an upward trend and at remaining depths of cut it is irregular, i.e., at lower depth of cut, as feed increases the Ra value increases. Figure 5(d) shows the effect of depth of cut at the selected levels of cutting speed without considering the feed rate. It is observed from the plot that for uncoated and coated tools, at lower cutting speed, the graph shows an upward trend and at remaining speeds it is not regular i.e., at lower cutting speed, as depth of cut increases the Ra value increases.

(a) Ra versus feed rate at the selected levels of cutting speed
(b) Ra versus cutting speed at selected levels of feed rates

(c) Ra versus feed rate at selected levels of depth of cut

(d) Ra versus depth of cut at the selected levels of cutting speed

(e) Ra versus cutting speed at the selected levels of depth of cut
Figure 5(e) shows the effect of cutting speed at the selected levels of depth of cut without considering the feed rate. It is observed from the plot that for uncoated and coated tool, at lower depth of cut, the graph shows an upward trend and at remaining depths of cut it is not regular i.e., at lower depth of cut, as cutting speed increases the Ra value increases. Figure 5(f) shows the effect of depth of cut at the selected levels of feed rate without considering the cutting speed. It is observed from the plot that for uncoated and coated tools, at all selected feeds, the graph is irregular, i.e., at all selected feed rates, as depth of cut increases the Ra value is irregular.

4. Optimization by differential evolution algorithm

The experimental results have been used to fit second-order response equations between the response variable (Ra) and the machining variables using Minitab software. Two response equations for the machining of stainless steel 304 using uncoated and coated carbide tool inserts under dry machining conditions were generated separately. The accuracy of the fit for the mathematical models as well as the significance of the individual model coefficients have been justified by performing the analysis of variance (Regression) and the F-ratio test. The adequacy of response variables is tested by conducting additional experiments. Equations (2) and (3) represent the surface roughness regression equations for turning of stainless steel 304 with uncoated and coated carbide tool inserts under dry conditions.

\[
R_a = 6.883 - 0.03483 x_0 - 41.91 x_1 - 1.779 x_2 - 0.01818 x_0 x_1 + 0.01391 x_0 x_2 - 5.523 x_1 x_2 + 0.000077 x_0 x_0 + 219.2 x_1 x_1 \quad (2)
\]

\[
R_a = 0.8693 - 0.000591 x_0 - 7.229 x_1 - 0.5020 x_2 + 0.05152 x_0 x_1 - 0.001603 x_0 x_2 + 6.839 x_1 x_2 + 0.000002 x_0 x_0 + 14.39 x_1 x_1 \quad (3)
\]

Figures 6 and 7 show that the predicted Ra values are a close match of experimental Ra values of uncoated and coated tool inserts. The corresponding average % errors were found to be 3.69% and 3.64% respectively. As the average percentage errors are well within minimum limit (5%), the second order equations can be optimized by DE.
Now two optimization problems are defined by considering each of the equations from (2) and (3) as the objectives to be optimized. Actually the expressions of Ra are minimized under the following bounds defined for the machining parameters.

\[
140 \text{ min} \leq x_0 \leq 224 \text{ m/min} ; \quad 0.1 \text{ mm/rev} \leq x_1 \leq 0.2 \text{ mm/rev} ; \quad 0.5 \text{ mm} \leq x_2 \leq 1.5 \text{ mm}
\]

4.1 Differential Evolution Algorithm

The DE algorithm is a population based algorithm which uses similar operators like crossover, mutation and selection operators as in genetic algorithms (GAs). While constructing better solutions, DE relies basically on mutation operation whereas GAs rely on crossover operation. Figure 8 shows a flow chart indicating the steps of DE algorithm [15] used in the work.

DE relies on random number generators for creating its parameters, viz., size of population (NP), crossover constant (CR) and mutation scaling factor (F). The maximum number of generations \((G_{\text{max}})\) used in the present study is 250. The DE parameters used in the optimization process are given in Table 5 which also shows the optimization results for the two models under consideration. It is found from the DE results of uncoated tool that, the optimum value of surface roughness corresponding to \(Vc^* = 140 \text{ m/min}, f^* = 0.1203 \text{ mm/rev}, d^* = 1.5 \text{ mm}\) is 0.59629 µm. It is found from the DE results of coated tool that, the optimum value of surface roughness corresponding to \(Vc^* = 139.99 \text{ m/min}, f^* = 0.1202 \text{ mm/rev}, d^* = 1.5 \text{ mm}\) is 0.56761 µm. The optimum results are cross checked by another non-traditional optimization algorithm called Genetic Algorithm (GA) and are given in the Table 5. The optimum results given by DE and GA are observed to be almost same.
**Figure 8.** Flowchart of DE

**Table 5.** Optimum results for Ra of stainless steel 304 with carbide tool insert.

| Algorithm | Parameters of algorithm | Optimum parameters | Optimum R\(_a\) (µm) |
|-----------|------------------------|--------------------|---------------------|
| DE        | CR = 0.9; F = 0.9      | \(V_c^* = 140\) m/min, \(f^* = 0.12\) mm/rev, \(d^* = 1.5\) mm | 0.59629, 0.56761 |
|           | NP = 60; \(G_{max} = 250\) | \(V_c^* = 140\) m/min, \(f^* = 0.2\) mm/rev, \(d^* = 0.5\) mm |              |
| GA        | \(s_p = 100; n_g = 250\) | \(V_c^* = 139.99\) m/min, \(f^* = 0.12\) mm/rev, \(d^* = 1.5\) mm | 0.59629, 0.56759 |
|           | \(p_c = 0.9; p_m = 0.09\) | \(V_c^* = 140\) m/min, \(f^* = 0.2\) mm/rev, \(d^* = 0.4999\) mm |              |

\(s_p\) – Population size; \(n_g\) – Number of generations; \(p_c\) – Crossover probability; \(p_m\) – Mutation probability

5. **Prediction of tool life**

Tool life of any cutting tool during machining of any work material is governed mainly by the level of three machining parameters i.e., cutting velocity (\(V_c\)), feed (\(f\)) and depth of cut (\(d\)). Taylor’s equation
for measurement of tool life is most commonly used in practice. Taylor proposed the following principle which governs the tool life and its dependence on cutting velocity.

\[ V_c.T^n = C \]  

(4)

where \( V_c = \) Cutting speed (m/min); \( T = \) Tool life (min)

\( n \& C = \) constants determined by the work & tool materials, tool design, etc.

Actually two stainless steel 304 specimens each of size ø80 mm x 250 mm long are taken to assess the tool lives of an uncoated and a coated carbide tools used in the experimentation. The parameters applied and the observations made during machining for calculating \( 'n' \) and \( 'C' \) values of tool life equation are mentioned in Table 6. Each of the specimens is machined till the tool resharpen criterion is reached. A total of 30 cuts were passed to reach that stage. The corresponding time (T) in minutes is recorded. Then by using the Taylor’s tool life equation (eq.4), the constants \( 'n' \) and \( 'C' \) with respect to uncoated and coated cutting tools are calculated. The corresponding results are also shown in Table 6. After ascertaining \( 'n' \) and \( 'C' \) values, the tool life is calculated (using Taylor’s Equation) with respect to the optimum cutting conditions and are shown in Table 7.

**Table 6. Calculated Values of \( 'n' \) and \( 'C' \) for machining with uncoated and coated tools.**

| Sample number | \( V_c \) in m/min | \( f \) in mm/rev | \( d \) in mm | Time (T) in min | Calculated value of \( n \) | Calculated value of \( C \) |
|---------------|---------------------|------------------|--------------|-----------------|----------------------------|-----------------------------|
|               |                     |                  |              |                 | Uncoated                  | Coated                      |
| 1             | 150                 | 0.15             | 1            | 43.18           | 77.66                     | 0.797                       | 0.508                       | 3015.86 | 1368.7 |
| 2             | 200                 | 0.15             | 1            | 30.18           | 44.23                     | 0.797                       | 0.508                       | 3015.86 | 1368.7 |

**Table 7. Tool life at optimum cutting conditions.**

| Optimum Cutting speed (\( V_c^* \)) in m/min | Tool life (\( T^* \)) in min |
|---------------------------------------------|-----------------------------|
|                                            | Uncoated                  | Coated                      |
| 140                                        | 47.080                     | 88.950                      |

6. Results and discussion

The optimization is carried out by DE with maximum number of generations equal to 250. Figure 9 shows the performance of DE for optimization of Ra for machining with uncoated and coated carbide tool inserts. The graphs show that the DE is converged to the optimum solutions in less than 50 generations with respect to the two models considered in this work. The optimum results of these two models are given in Table 8.

![Figure 9. Convergence graph of DE for surface roughness](image-url)
Finally two confirmation tests with regard to Ra for machining of stainless steel 304 with uncoated and coated carbide tools are conducted on two individual specimens under optimum machining conditions ($V_\text{c}$*, $f$*,$d$*) obtained by DE. The experimental results and the corresponding percentage errors are calculated and furnished in Table 8. The percentage error is found to be around 5.36% and 3.8% for surface roughness of stainless steel 304 when machining with uncoated and coated tools.

| Cutting tool | DE parameters | Optimum parameters | $R_a$ value ($\mu$m) | % error |
|-------------|----------------|--------------------|----------------------|---------|
|             |                | $V_\text{c}$ = 140 m/min |                      |         |
|             |                | $f$ = 0.12 mm/rev |                      |         |
|             |                | $d$ = 1.5 mm |                      |         |
| Uncoated    | CR = 0.9; F = 0.9 | NP = 60; $G_{\text{max}}$ = 250 | 0.596 | 5.36 |
|             |                | $V_\text{c}$ = 140 m/min |                      |         |
|             |                | $f$ = 0.2 mm/rev |                      |         |
|             |                | $d$ = 0.5 mm |                      |         |
| Coated      | CR = 0.9; F = 0.9 | NP = 60; $G_{\text{max}}$ = 250 | 0.567 | 3.8  |

7. Conclusions

In this work an approach is presented in which mathematical models have been developed based on experimental results of surface roughness of stainless steel 304 when turning operation is done with uncoated and coated carbide cutting tools under dry machining conditions. The predicted values of surface roughness are compared to their corresponding measured experimental values. It is found that, the feed rate is an influential parameter with respect to surface roughness. Actually as the feed rate increases, the surface roughness increases, and as the cutting speed increases, the surface roughness decreases. But due to chatter or vibrations, surface roughness increased slightly with increase in cutting speed where as the effect of depth of cut is not regular.

The optimum values of Ra obtained by DE for uncoated and TiAlN coated carbide tools are found to be 0.596 $\mu$m and 0.567 $\mu$m respectively. Also the optimum values of tool life at optimum surface roughness condition are found to be 47.08 min. and 88.95 min. for uncoated and coated cutting tools respectively. The percentage improvement in surface roughness is found to be 4.87%. Also the percentage improvement in tool life at optimum surface roughness condition is found to be 88.93%.

8. References

[1] Abhijeet S. Morea, Wenping Jiang, W.D. Brownb, and Ajay P. Malshe, 2006, Tool wear and machining performance of CBN–TiN coated carbide inserts and PCBN compact inserts in turning AISI 4340 hardened steel, Journal of Materials Processing Technology.180, 253–262.

[2] Chakraborty Pinaki, 2008, "Tool Life and Flank Wear Modeling of Physical Vapour Deposited TiAlN/TiN Multilayer Coated Carbide End Mill Inserts when Machining 4340 Steel Under Dry and Semi-Dry Cutting Conditions", Open Access Dissertations Journal, 22.

[3] Devillez.A, Schneider.F, Dominiak.S, Dudzinski.D and Larrouquere.D, 2007, “Cutting forces and wear in dry machining of Inconel 718 with coated carbide tools”, Wear, 262, 931–942.

[4] Ghani J.A., I.A. Choudhury and H.H. Masjuki. 2004, “Wear mechanism of TiN coated carbide and uncoated cermet tools at high cutting speed applications”, Journal of Materials Processing Technology 153–154, 1067–1073.

[5] Harish C. Barshilia, Moumita Ghosh, Shashidhara, Raja Ramakrishna and Rajam K.S, 2010, Deposition and characterization of TiAlSiN nanocomposite coatings prepared by reactive
pulsed direct current unbalanced magnetron sputtering, Journal of Applied Surface Science, 256, 6420–6426.

[6] Ibrahim Çiftci, 2006, “Machining of austenitic stainless steels using CVD multi-layer coated cemented carbide tools”, Tribology International, 39, 565–569.

[7] Jeong Suk Kim, Gyeng Joong Kim, Myung Chang Kang, Jung Wook Kimb, and Kwang Ho Kim, 2005, Cutting performance of Ti–Al–Si–N-coated tool by a hybrid-coating system for high-hardened materials, Surface & Coatings Technology, 193, 249–254.

[8] Narasimha.M, Reiji Kumar.R, and Achamyelehaemro Kassie, 2013, Performance of Coated Carbide Tools, The International Journal Of Engineering And Science (IJES), 2, Issue 6, 47-54.

[9] Narasimhu Andriya, Member, IAENG, Venkateswara Rao.P, and Sudarsan Ghosh, 2012, Dry Machining of Ti-6Al-4V using PVD Coated TiAlN Tools, Proceedings of the World Congress on Engineering (WCE), 3.

[10] Nur Akmal Hakim Bin Jasni, 2013, Cutting performance of advanced multilayer coated (TiAlN/ AlCrN) in machining of aisi d2 hardened steel, Universiti Tun Hussein Onn Malaysia.

[11] Ran Ji, University of Birmingham, Development and characterization of Nano-multilayer CrAlsIn coating systems for cutting tools.

[12] Reginaldo T. Coelho, Eu-Gene Ng and Elbestawi.M.A, 2007, Tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions, International Journal of Machine Tools & Manufacture, 47, 263–272.

[13] Renato Franc os de A vila, Alexandre Mendes Abraço, Cristina Duras de and Godoy.G, 2006, The performance of TiN coated carbide tools when turning AISI 8620 steel, Journal of Materials Processing Technology, 179, 161–164.

[14] Sergio Baragetti, and Federico Tordini, 2011, A Review of the Fatigue Behaviour of Components Coated with Thin Hard Corrosion-Resistant Coatings, The Open Corrosion Journal, 4, 9-17.

[15] Storn.R and Price.K.V, 1997, Differential Evolution – A simple and efficient heuristic for global optimization over continuous spaces, J.Global Optimization, 11, 341-359.

[16] Vikas Chawla, 2013, Corrosion Behavior of Nanostructured TiAlN and AlCrN Thin Coatings on ASTM-SA213-T-11 Boiler Steel in Simulated Salt Fog Conditions, Journal of Materials Science and Metallurgy Engineering, 1, No. 2, 31-36.

[17] Vikram Kumar.CH.R, Kesavan Nair.P, and Ramamoorthy.B, 2008, Performance of TiCN and TiAlN tools in machining hardened steel under dry, wet and minimum fluid application, Int. J. Machining and Machinability of Materials, 3, 132-142.