2005-01-01

Micro Shot Blasting of Machine Tools for Improving Surface Finish and Reducing Cutting Forces in Manufacturing

James Vahey
Technological University Dublin

David Kennedy
Technological University Dublin, david.kennedy@tudublin.ie

Follow this and additional works at: <https://arrow.tudublin.ie/engschmecart>

Part of the [Mechanical Engineering Commons](#)

Recommended Citation

Vahey, J., Kennedy, D.: Micro Shot Blasting of Machine Tools for Improving Surface Finish and Reducing Cutting Forces in Manufacturing. *Materials & Design*, Vol. 26, 2005, p.203-208. doi:10.1016/j.matdes.2004.02.013

This Article is brought to you for free and open access by the School of Mechanical and Design Engineering at ARROW@TU Dublin. It has been accepted for inclusion in Articles by an authorized administrator of ARROW@TU Dublin. For more information, please contact arrow.admin@tudublin.ie, aisling.coyne@tudublin.ie, gerard.connolly@tudublin.ie.

Micro shot blasting of machine tools for improving surface finish and reducing cutting forces in manufacturing

J. Vahey and D. Kennedy.
Dublin Institute of Technology,
Bolton Street,
Dublin 1.

Published by Materials & Design, 26 (2005) 203-208

Abstract

Micro blasting of cutting tips and tools is a very effective and reliable method of advancing the life of tools under the action of turning, milling, drilling, punching and cutting. This paper outlines the ways in which micro blasted tools, both coated and uncoated have benefited from shot blasting and resulted in greater productivity, lower cutting forces, improved surface finish of the work pieces and less machine downtime. The process of micro blasting is discussed in the paper. Its effectiveness depends on many parameters including the shot media ad size, the mechanics of impact and the application of the shot via the micro shot blasting unit. Control of the process to provide repeatability and reliability in the shot blasting unit is discussed. Comparisons between treated and untreated cutting tools are made and results of tool life for these cutting tips outlined. The process has shown to be of major benefit to tool life improvement as outlined in the paper.

Keywords: Micro Shot Blasting, surface finish, machine tools.

Introduction

Many modern techniques have been developed to enhance the life of components in service such as alloying additions, heat treatment, surface engineering, surface coating, implantation process, laser treatment and surface shape design. Processes such as thin film technology, plasma spraying, vacuum techniques depositing a range of multi-layered coatings have greatly enhanced the life, use and applications of engineering components and machine tools. Bombardment of components with millions of micro-shot ranging in size from 4 μ m to 50 μ m with a controlled process can lead to dramatic operating life improvements of such components. Standard shot peening was first used in an production process to extend the life of valve springs for Buick and Cadillac engines in the early 1930's [1,2] but prior to this it was a well known process used by blacksmiths and sword makers over time to improve the

toughness of the cutting edges of their weapons. Cutting tips and tools can be greatly improved by the process of Micro Shot Blasting their surfaces to induce compressive residual stresses. The operating life of tools such as drills, turning tips, milling tips, punches, knife edges, slicers, blades, and a range of other working parts can benefit from this process.

Other components such as springs, dies, shafts, cams, and dynamic components in machines and engines can be enhanced by this process. Fatigue life of compressor components treated by shot peening have increased dramatically as reported by Eckersley and Ferrelli [3].

Other factors such as improved fatigue resistance, micro-crack closure, reduced corrosion and an improved surface finish can also be designed into components as a result of this process.

Not only can an improvement be made to the surface finish of the cutting tips and tools but also the surface finish of the work pieces machined with these tools have improved as a result of this technique.

Engineering materials such as tools steels, carbides, ceramics, coated carbides, through to polymers and rubbers can benefit from this process.

The key requirement for this process is to develop an automated micro-blasting process to fit inside a spray booth or standard shot blasting booth.

Shot material, size and mass, operating pressures, operating velocities, kinetic energy, density and coverage time will need to be perfected and optimised for a range of materials. The process is a line of sight method and can be applied to complex shapes such as the tips of drill bits.

Method of operation

One of the primary ways that components fail in service is through fatigue. This is closely associated with cyclic stresses and accelerated by tensile stresses, micro crack propagation and stress corrosion cracking. Cracks reduce the cross section of a material and eventually it will fail to support the loading applied. One simple method of reducing failure by fatigue is to arrest these tensile stresses by inducing compressive stresses into a surface. The benefits obtained with shot peening is a direct result of the residual compressive stresses produced in a component. A typical shot striking a surface is shown in Figure 1. Any applied tensile loads would have to

overcome the residual compressive stresses before a crack could initiate according to Almen [4].

Poor machining of materials can result in residual stresses accruing at the surface.

Rough surfaces have deeper notches, where cracks can initiate due to tensile stress concentrations at these points.

Many standard machining processes such as grinding, milling, turning, and coating processes such as electroplating induce residual tensile stresses in surfaces and this can lead to early failure of components treated by these processes. Further tensile loading in service would lead to early failure of this can be prevented by shot peening and micro blasting of component surfaces.

Micro shot blasting will change the following properties of a materials surface:

- i. Resistance to fatigue fracture
- ii. Resistance to stress corrosion
- iii. A change in residual stresses
- iv. Modification of surface finish

It is a cold working process involving bombarding powders such as ceramics, glass and metals of mainly spherical shapes against surfaces and can be used in conjunction with other processes. The main stages involved in this dynamic process include elastic recovery of the substrate after impact, some plastic deformation of the substrate if the impact pressure exceeds the yield stress, increased plastic deformation due to an increase in pressure and finally some rebound of the indenter due to a release of elastic energy. Some critical design characteristics of the micro shot peening process include the shot size, shape, hardness, density, durability, angle of impact, velocity and intensity. All of these parameters will influence the residual compressive stresses produced in the substrate.

Figure 1. Shot peening process.

Experimental work

Tool materials such as Tungsten Carbide, High Speed Steels used in milling and turning tools were subjected to the micro blasting process using different shot media (ceramic and glass bead) and shot size. Tests prior to and following the blasting process were conducted to ascertain any improvements resulting from the process. The micro-shot peening unit is shown in Photograph 1. It incorporates an air filter, pressure regulator and gauge, air flow regulator, pressurized blast media container and a venturi blast nozzle for directing the stream of micro shot. The unit is PLC controlled and a stepper motor, used to drive a lead screw is used to move the blast nozzle across the sample in order to control media shot coverage. The blast nozzle can also be rotated to allow the shot media to strike the samples at different angles. Tests undertaken include surface finish and roughness, machining tests on standard lathes and mills, hardness tests, cutting forces on turning operations, tool wear and the surface finish of the work pieces machined. Figures 2. and 3. show a typical High Speed Steel tip prior to and following the micro shot peening process using ceramic bead at a pressure of 5.5 Bar.

Photograph 1. Micro shot peening unit

Figure 2. High Speed Steel Tip Prior to Treatment.

Figure 3. High Speed Steel Tip post treatment.

Experimental results

Testing of treated and untreated cutting tips and tools was conducted on High Speed Steels for turning and milling as well as coated and uncoated carbide inserts. A dynamometer was used to measure cutting forces on the turning tool (Lathe). The cutting process consisted of a depth of cut of 2mm on a standard Bright Mild Steel specimen over a length of 750mm while milling tests consisted of machining a 25mm * 25mm * 150mm piece of mild steel using a depth of cut of 1mm with a slot milling cutter of 18mm diameter. Surface roughness measurements were conducted on the machined components prior to and after machining to establish whether the treated cutting tips performed any better than the untreated tips. Micro Hardness testing was also carried out to establish if there was any increase in surface hardness due to the micro shot peening process.

The impact angle of the shot was set at 90° as this should give the optimum compressive layer [5]. The shot velocity on impact with a surface is largely dependent on the nozzle size, the air pressure and the distance from the substrate. The exposure time was adequate to give sufficient coverage of the substrate and this was determined by the Almen strip Saturation time, work piece indentation time and visual appearance. Harder materials such as carbides will obviously require longer exposure time or harder shot media.

The micro peening media used was a ceramic bead of approximately 40µm diameter providing high impact strength and hardness (NF L 06-824, approximately 60 HR_c).

Micro-Hardness tests

Combined Vickers Micro Hardness tests gave the results in Table 1. for both treated and untreated High Speed Steel (HSS)cutting tips.

Sample	MH _V (1000g)
Untreated High Speed Steel	936
Treated High Speed Steel	963
Untreated Carbide tip	1318
Treated Carbide tip	1388

Table 1. Vickers Micro Hardness values

Surface Roughness Values

In all surface roughness tests conducted, the micro-blasted surface gave an improved surface roughness value. Surface roughness and profile tests were carried out on both a Talyor Hobson Tallysurf instrument and a non contact surface profileometer.

Surface roughness details of a typical untreated High Speed Steel cutting tip and a treated one are shown in Figures 4. and 5. and Table 2. shows the results of surface measurement values for other cutting tips and tools and workpieces.

Figure 4. Surface values for untreated HSS.

Figure 5. Surface values for treated HSS

Sample	Treated/Untreated	Ra Value	Test method
Milled surface carbide tool. 225s cutting	Untreated	2.2	Tallysurf
Milled surface carbide tool. 225s cutting	Treated	1.8	Tallysurf
Milled surface HSS 450s cutting	Untreated	5.4	Tallysurf
Milled surface HSS after 450s cutting.	Treated	4.9	Tallysurf
Turned surface uncoated carbide tip after 30s cutting	Untreated	3.0	Tallysurf
Turned surface uncoated carbide tip after 30s cutting	Treated	2.7	Tallysurf
Turned surface coated carbide tip after 30s cutting	Untreated	2.8	Tallysurf
Turned surface coated carbide tip after 30s cutting	Treated	2.5	Tallysurf
Turned surface coated carbide tip after 2535s cutting	Untreated	6.2	Tallysurf
Turned surface coated carbide tip after 2535s cutting	Treated	3.8	Tallysurf
Turned surface HSS. 2568s cutting	Untreated	6.0	Tallysurf
Turned surface HSS. 2568s cutting	Treated	4.7	Tallysurf
Drilled surface	Untreated	2.2	Profileometer
Drilled surface	Treated	1.024	Profileometer

Table 2. R_a values for work pieces.

Figure 6. shows an uncoated carbide cutting tip which was not subjected to micro blasting. The flank wear was measured using an optical microscope and the value recorded was 150 μ m after 676 seconds of machining. Figure 7. shows an uncoated carbide tip subjected to micro blasting. The flank wear in this case is only 90 μ m for the same machining time.

Figure 6. Flank wear on untreated carbide tip after 2535 seconds of turning.

Figure 7. Flank wear on treated carbide tip after 2535 seconds of turning.

Dynamometer tests

Figures 8. and 9. show the comparison for Dynamometer results for High Speed Steel in the treated(micro blasted) and untreated states with relevant comments.

Similar profiles are shown for coated and uncoated turning tips in both the treated (micro blasted) and untreated conditions in Figures 10. to 13.

In all cases, the micro blasted tips provided an increase in cutting tip life with lower cutting forces recorded.

cut	dynamometer	Rpm	Depth of Cut	Cutting Time	Comments	
	microns		mm	Seconds		
1	0.071	198	2 X 750	642		
2	0.071	204	2 X 750	1284		
3	0.071	208	2 X 750	1926		
4	0.073	212	2 X 750	2568	Finish Good	
5	0.076	216	2 X 750	3210	Deterioration	
6	0.079	220	2 X 750	3852	Built up edge failing Tip Failure	

Figure 8. Dynamometer results for micro blasted HSS

Cut no	Dynamometer (Microns)	Rpm	Depth of Cut (mm)	Cutting Time (Seconds)	Comments	
1	0.074	198	2 X 750	642		
2	0.074	204	2 X 750	1284		
3	0.076	208	2 X 750	1926	cutting edge failing	
4	0.081	212	2 X 750	2568	built up edge	
					tip failure	

Figure 9. Dynamometer readings for untreated HSS

cut	dynamometer	rpm	Depth of Cut	Cutting Time	Comments	
	microns		mm	Seconds		
1	0.076	1061	2 X 750	169		
2	0.076	1091	2 X 750	338		
3	0.076	1121	2 X 750	507		
4	0.076	1151	2 X 750	676		
5	0.076	1181	2 X 750	845		
6	0.079	1211	2 X 750	1014		
7	0.079	1241	2 X 750	1183		
8	0.079	1271	2 X 750	1352		
9	0.079	1301	2 X 750	1521		
10	0.081	1331	2 X 750	1690		
11	0.081	1361	2 X 750	1859		
12	0.081	1391	2 X 750	2028		
13	0.081	1421	2 X 750	2197	built up edge failing	
14	0.084	1451	2 X 750	2366	tip at end of life	
15	0.086	1481	2 X 750	2535	tip failure	

Figure 10. Dynamometer Results for micro blasted coated carbide tip.

cut	dynamometer	rpm	Depth of Cut	Cutting Time	Comments	
	microns		mm	Seconds		
1	0.083	1061	2 X 750	169		
2	0.083	1091	2 X 750	338		
3	0.083	1121	2 X 750	507		
4	0.083	1151	2 X 750	676		
5	0.083	1181	2 X 750	845		
6	0.083	1211	2 X 750	1014	sparks from tip built up edge failing tip at end of life	
7	0.083	1241	2 X 750	1183		
8	0.084	1271	2 X 750	1352		
9	0.086	1301	2 X 750	1521		
10	0.086	1331	2 X 750	1690		
11	0.089	1361	2 X 750	1859		
12	0.089	1391	2 X 750	2028		
13	0.091	1421	2 X 750	2197		
14	0.095	1451	2 X 750	2366	tip failing rapidly	
15	0.096	1481	2 X 750	2535		

Figure 11. Dynamometer readings for untreated coated carbide tip

cut	dynamometer		rpm	Depth of Cut	Cutting Time	Comments	
	microns			mm	Seconds		
1	0.061		1061	2 X 750	169		
2	0.064		1091	2 X 750	338		
3	0.066		1121	2 X 750	507		
4	0.069		1151	2 X 750	676	good finish	
						sparks from tip	
						BUE failing	
						Tip at end of life	

Figure 12. Dynamometer results for micro blasted uncoated carbide tip.

cut	dynamometer		rpm	Depth of Cut	Cutting Time	Comments	
	microns			mm	Seconds		
1	0.069		1061	2 X 750	169		
2	0.071		1091	2 X 750	338		
3	0.074		1121	2 X 750	507	sparks from tip	
						BUE failing	
						tip at end of life	

Figure 13. Dynamometer results for untreated uncoated carbide tip.

Conclusions

This research work has shown that micro shot blasting of cutting tips and tools has a very positive effect on surfaces by increasing toughness, operating life, improving hardness and surface finish. From the tests conducted, it is obvious that the process effects the residual stresses at or near the surface in a beneficial way by inducing compressive stresses on the substrates tested. The micro blasting process is very simple to apply and economical to use. The mechanical properties of the substrates will determine the type of treatment, i.e. shot hardness, velocity and duration of application in order to obtain maximum benefits from this process. In some cases, authors have reported a 4 to 10 fold improvement in fatigue life in a range of dynamic machine parts subjected to standard shot blasting. Further testing will need to be conducted at the micro shot blasting stage to obtain similar benefits.

Other applications for the micro blasting process are currently being investigated by this team and rubber based products that are subjected to fatigue wear are being tested in order to remove the surface voids that produce stress concentrations areas in these materials.

References

- [1] "Impact, Fall 1989, Metal Improvement Company, Bloomfield, Connecticut.
- [2] F.P. Zimmerli, Heat Treating, Setting and Shot-Peening of Mechanical Springs", Metal Process, June 1952.
- [3] J.S. Eckersley & Buzz Ferrelli, Using Shot Peening to multiply the Life of Compressor Components, The Shot Peener, International Newsletter for Shot Peening-Surface Finishing Industry, Volum 9, Issue 1, March 1995.
- [4] "J.O. Almen on Shot Blasting", J.C. Alme, General Motors Test, U.S. Patent 2,350,440.
- [5] Jack Champaigne, "controlled Shot Peening", Elec Inc. 1989, Report.