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Material and EnergyWastes Minimization in a Machining System: A Review

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Abstract
In the present scenario productivity of the organization is to be increased while keeping in view economy and environment. One of the methods to achieve this is to minimize waste. Machining is a process where excess material is removed with the help of a cutting tool to give useful product/services. So it can be wasteful in its use of both materials and energy. Productivity can be increased using waste minimization approaches. In this paper a review of such approaches has been made.

Keywords: machining system, waste minimization, cutting fluid, cutting tool, energy losses

1. Introduction

Machining is a material removal process that involves the cutting away of surplus materials using various cutting tools to obtain the part as per specification. For the context of this paper the term machining will refer to processes such as milling, turning, drilling, sawing etc. To coordinate the activities of the above processes the concept of machining system has been developed. In machining system a work piece with the aid of a machine tool and cutting tool is transformed into a product.However during transformation process some undesirable products/activities are also produced which also consume resources or create costs without generating any form of value in any work system. These are called wastes.

Wastes represent loss of resources and money along with bad effects on environment. Minimization of wastes is one of the important issues due to present requirement of environmental protection and also to meet competition. By minimizing waste, the firm can reduce waste disposal costs and material requirement, avoid environmental fines, boost profits, protect and improve the state of environment. Avoidance of waste is equivalent to resources produced.So waste minimization becomes influencing factor in the design of products and processes.

Through waste minimization the productivity in the existing system may be increased. In this paper the various wastes of a machining system and their effects and also the various waste minimization approaches have been discussed.

2. Types of machining wastes and their effects

In a machining process material wastes (solid, liquid, and vapor) and energy waste are generated. Solid wastes are work material wastes in the form of chips, expended cutting tool, worn out tool particles. Liquid and vapor wastes are cutting fluid waste. Energy waste is excessive use of energy and its loss in the form of heat, noise and vibrations. The wastes in machining process have following effects:

1. Wastes in the form of chips and expended cutting tools cause depletion of natural resources more rapidly.
2. Cutting fluids wastes have economic impact on machining process and create health hazards.Considerable amount of cutting fluid is lost from the manufacturing system through vaporization, loss with chips, work piece and machine components[1].
3. Wastage of energy causes more generation of electricity from non-renewable sources. It creates problem like global warming, ozone layer depletion etc.
4. Productivity of the system decreases as waste is an undesirable output.

So there is a need to minimise wastes in a machining system. The various approaches are discussed below.

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3. Waste minimization approaches

Waste minimization options [2] are as follows:

1. Reduction or elimination of waste at the source, usually within a process
2. Recycle and reuse
3. Improving the quality of waste generated.

In 1950s one common response to industrial wastes was to ignore them. This was possible when the problems were relatively small, awareness of the health and environmental impact was not high. In 1960s a common approach to waste was to dilute and disperse. Later on when the environmental assimilative capacity for pollutants was exceeded, there were efforts to establish environmental standard to regulate the waste. Then the treatment system was introduced to ensure that the waste met the environmental quality standard but it involves cost. Industry then began exploring technological options to reduce waste at source [3]. In the literature approaches for waste minimization in machining process based on reduction and elimination of waste at source have been reported. Those approaches are discussed below.

3.1For liquid waste

Cutting fluid is the liquid waste. The temperature and friction at the cutting zone adversely affects the performance. To control this cutting fluid has been used but it is uneconomical, creates problem of its disposal and environmental pollution etc.So the alternative methods have been developed to reduce or eliminate the use of cutting fluid. These are:

3.1.1 Dry Machining:

Machining without cutting fluid is called dry machining. In this there is no pollution, no disposal cost and no danger to health. But heat generation affects both tool and work piece. Its dimensional control becomes difficult. There will be more friction and adhesion between the tool and the work piece due to higher pressure with increased tool wear and reduction in tool life [4]. This technique is less effective when higher machining efficiency, better surface finish quality and severe cutting conditions are required. The tool can be isolated from work piece by introducing protective layer on tool face [5].The cast material in general grey C.I. are particularly well suited for the dry machining due to short chips, low cutting temperature and forces and lubricating effect of the embedded graphite[6].Problems like chips removal and jamming occur in drilling [4].

3.1.2 Cryogenic machining

Cryogenic machining is an innovative method of cooling the cutting tool during machining. Coolant is usually nitrogen fluid which is liquefied by cooling to -196^0 C.It evaporates harmlessly into the air requiring no disposal. Chip generated have no residual oil on them and can be recycled as scrap metal [7]. It is a sustainable machining having increased material removal rate without increase in tool wear and with reduced changeover cost, resulting higher productivity, improved surface quality and increased tool life due to lower abrasion and chemical wear[8].Cryogenic cooling is generally used to machine heat resistant alloys used in the manufacturing of aero engine component[9]. Even though the initial cost and effort involved with cryogenic machine are higher, cryogenic machining is cheaper in comparison to conventional machining and this trend is more dominant if high cutting speeds are employed because of less tool changing [10].

3.1.3 Use of minimum quantity lubricant

Minimum quantity lubricant (MQL) refers to the use of a very small lubricant flow 50-500 ml/hr[11]. The mixture of vegetable oil or biodegradable synthetic ester is sprayed on the tool tip with compressed air. A good level of lubrication is guaranteed, but the cooling action is very small. The chip is removed by the air flow used to spread the lubricant. If the mixture is not properly controlled it may lead to the formation of mist or dangerous vapors and thus contamination of working environment.MQL technique was found better in some other applications along turning [12, 13, 14].

3.1.4High pressure jet assisted machining

High pressure jet assisted machining (HPJAM) relates to delivering the oil based or water based cooling and lubricant fluid in relatively small flow rates under extremely high pressure up to 300 MPa to the cutting tool tip.

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Cutting fluid under such pressure can penetrate closer to shear zone, provide improved lubrication, cooling and chip breaking effects. This action leads to a reduction of the seizure region, thus lowering the friction coefficient which in turn results in reduction in cutting temperature and cutting forces [15, 16, 17].

3.1.5 Use of solid lubricant

Solid lubricant is another alternative which provides cooling economically without creating pollution and maintaining machining quality. It gives good performance in end milling and turning [18,19, 20].

In the above techniques cutting fluid eliminated (dry machining), reduced (MQL, HPJAM) or some alternative methods (Cryogenic machining, solid lubricants) are used .Some techniques involve additional cost. But their advantages overcome the additional cost. They perform satisfactorily as per their cutting tool work piece combinations.

3.2For solid waste

Solid wastes include worn out tool, tool particles and chips. Estimates of scrap in machining range from 10% to 60% [21]. Some of the techniques used to reduce the solid wastes are:

3.2.1 For work piece

3.2.1.1 Near net shape (NNS)

For optimizing the use of work material NNS has been suggested [1].In this technique semi-finished product is produced, as near as possible to their definite shape and contour. So cutting operations are confined to the finishing steps. NNS parts significantly reduce raw material usage, machining time and energy consumption.NNS technologies can be used for high cost material such as titanium and nickel alloys, and also high volume production of low cost material such as low alloy steel [22].In a case study the traditional process produced about 3.8 kg of waste for each piece compared to an almost none waste production by the NNS process[23].Due to low cutting depth in NNS turning, most of the heat generated is concentrated on a small area of the cutting tool. This generates high tool wear as well as difficulties in chip control [22].

3.2.2For cutting tools

There are primarily three problems faced by all cutting tools: wear at the cutting edge, heat generated during cutting process, and thermo mechanical shock. During the cutting process wear takes place at the rake as well as flank face of the tool. As a result tool wastes are produced in the form of expended cutting tool and tool particles. To minimize the tool waste ultrasonically assisted machining, hot machining, lubricant/hard coatings of tool and use of cutting fluid are suggested [5, 24].

3.2.2.1 Ultrasonic assisted turning

In Ultrasonic assisted turning (UAT) cutting edge of the tool is vibrated at a high frequency of around 20 kHz and amplitude of around 10 µm.It is used for high precision machining application and for difficult to cut materials machining such as hardened steels, nickel based alloys, titanium etc. As the ultrasonic assisted tool has no continuous contact with the work piece due to this cutting force is lower than in conventional cutting [24,25].Such an intermittent contact also leads to a reduction in the total time of thermal conduction between cutting tool and chip, and cooling owing to the convective heat transfer to the environment[24].A significant reduction of cutting forces, tool wear and surface finish improvement has been reported of nickel and titanium based alloys[26,27]..

The initial cost of UAT setup is high.Fitting different tool holders or cutting tips requires readjustment of theoscillator frequency to match the changes in mechanical properties of vibrating system. A highly rigid machine tool /tool post is required for UAT [24].

3.2.2.2. Hot machining

In hot machining partial or whole work piece is heated before or during the machining using flame heating, plasmaheating, electrical resistance heating or laser assisted heating. It is generally used for difficult to cut materials. Considerable decrease in flank wear and a significant effect on tool life have been reported [28,29].This may be due to decrease in yield stress of the work piece. But high work piece temperature may cause increasing tool wear rate, so optimum temperature should be selected [30].The limiting highest temperature will be the recrystallization temperature of the work piece.The tool heating also takes place, which leads to deteriorated performance of the tool, so cooling of the cutting tool is very effective for reducing the tool wear [31].

3.2.2.3 Coating of tools:

Heat generated in machining processes strongly influences the tool performance. To increase tool life its cutting surface may be coated with material that provide minor wear with thermal isolation feature. The principal coating materials according to Shaw are as follows: Titanium Nitride (TiN) to lower friction and built up edge, TiC to increase hardness and Al_2O_3 to provide a thermal barrier. Cemented carbide tools coated with TiC, TiN or TiAlNi can show an increase of service lifetime of tools by a factor of ten compared to uncoated tools [32]. Tool material composition and properties affect machining forces, tool life and surface roughness [33,34].

3.2.2.4 Use of cutting fluid:

Cutting fluid applied during machining performs both coolant and lubricant functions simultaneously. It removes heat by carrying it away from the cutting tool /work piece interface [35].This cooling effect prevents the tool from exceeding its critical temperature range beyond which the tool softens and wear rapidly [36].Lubricating action of it decreases cutting forces. Several technique have been developed in order to increase overall effectiveness of the process like cryogenic machining, minimum quantity lubrication, high pressure jet assisted machining and solid lubricants etc. A substantial improvement in tool life was obtained under cryogenic machining compare to dry and wet machining due to reduction in temperature at cutting zone[37,38,39,40,41,42].In MQL application heat transfer is predominantly in evaporative mode which is more efficient than convective heat transfer prevalent in conventional wet turning [43,44].It is observed that solid lubricant improves the process performance by reducing cutting forces and tool flank wear [45]. In HPJAM due to better penetration of fluid into the tool wok piece and tool chip contact region better cooling effect and decrease in tool wear occur [46,47].

3.3 For energy waste

Wastage of energy may be associated with geometry of work piece, machining process, energy losses in machine tool in the form of heat, noise and vibration etc [48]. The energy efficiency analysis shows that newer machine tools can be more efficient than older machine tool resulting in energy saving during material removal [49]. Energy efficiency of existing machine can be improved by the optimization methodology in case of shortage of funds [50]. Vibration causes loss in energy and also affects surface finish and tool wear.Choudhury et al. [51] developed a system for on line vibration control. Due to significant improvement in the dynamic characteristics of the machine tool higher productivity, dimensional accuracy and surface finish was obtained.
No significant work has been reported considering the effect of noise, vibration and heat in energy losses during machining. Iskra et al. [52] investigated the energy balance of an orthogonal cutting process and showed that about 28% of the total input energy undergoes as waste in the form of heat energy. However vibration and noise do not play significant role in wastage of energy.

Conclusion

It is important to achieve economic growth while protecting the environment. One method of it is waste minimization. In machining process excess material is removed in the form of chips, so it can be wasteful in its use of both material and energy. Various techniques like dry machining, MQL, HPJAM, cryogenic machining have been reported in the literature to reduce or eliminate the use of cutting fluid. Work on NNS for saving raw material and UAT, hot machining, coating of tool, cutting fluid are used to reduce or eliminate cutting tool waste. On line monitoring of process and improvement of existing machine tool can reduce energy waste.Research in the area of machining has been focused on process level activities and their improvements for waste minimization, including optimizing material use, minimizing the use of cutting fluid and reducing cutting energy.It is observed that design parameter (part geometry) and energy losses in the form of heat, noise, vibration have not been considered. Enough work has not been done while considering system level approach. It is important to view machining as a system consisting of the work piece, the cutting tool and machine tool. Cutting operations cannot be carried out efficiently and economically without knowledge of the interactions among these elements. So there is a need to further make studies on different aspects of waste minimization and develop a mathematical model to predict the behavior and performance of the machining system and to select the parameters for minimization of waste.

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