Effect of Process Parameters on Machinability of Aluminum Alloys (Al-Fe-V-Si)

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ABSTRACT

Machinability is the most important property of a material. There are various ways to check the machinabilty of a material. The large number of machinability tests developed in the past is limited by their ability to compare materials of different classes, eg. Ferrous vs. non-ferrous metals, The considerations involved in the successful machining of aluminum and its alloys have sprung into particular prominence during the last year or so with the greatly increased use of these materials under the armaments expansion program. Numerous firms who have hitherto confined their attentions to steels and non-ferrous metals like brass and copper are now engaged in the mass production of parts machined from extruded, rolled and cast aluminum and aluminum alloys. These light metals are by no means difficult to machine but their particular properties require a special technique if full advantage is to be taken of the economy resulting from the high Speed at which they may be worked. There are many factors which affect the machinability and other properties of the material. In current research work it is experimentally studies and investigated the effect of such parameters (depth of cut, feed rate, cutting speed, cutting force etc) on the properties of Aluminium base alloy (Al-Fe-V-Si)

INTRODUCTION

Machining operations have been the core of the manufacturing industry since the industrial revolution. Manufacturing industries strive to achieve either a minimum cost of production or a maximum production rate, or an optimum combination of both, along with better product quality in machining. These goals have importance in the context of economic liberalization and globalization. Generally, a manufacturing process for a product consists of several phases, such as product design, process planning, machining operations, and quality control. The machinability aspect is related to all phases of manufacturing, especially to process planning and machining operations. Machinability is a measure of ease with which a work material can satisfactorily be machined. The machinability aspect is of considerable importance for production engineers so that the processing can be planned in an efficient manner [1]. The study can also be a basis for cutting tool and cutting fluid performance evaluation and machining parameter optimization. In the process of product design, material selection is important for realizing design objectives and for reducing the production cost. Due to its influence on the cost of production, the machinability of work materials needs to be taken into account in the product design. But it will not always be a top priority-criterion in the process of materials selection. If there are a finite number of work materials from which the best is to be chosen, and if each work material satisfies the required design and functionality of the product, then the main criterion to choose the work material is its machinability – its operational performance during machining.

Machinability is influenced by a number of variables, such as the inherent properties or characteristics of the work materials, cutting tool material, tool geometry, the nature of tool engagement with the work, cutting conditions, type of cutting,type of cutting fluid used, and machine tool rigidity and its capacity [2]. These variables are the machining process input variables and independent of the machining process. On the other hand, the machining process output is marked by dependent process variables, such as tool life (or tool wear), cutting forces, specific power consumption, processed surface finish, dimensional accuracy, temperature generated, noise, vibration, and chip formation.[3]. The dependent process variables are the functions of process input variables and refer to the performance of work material during machining operation in terms of technical and economic consequences, and are directly related to machining operations, and hence to machinability. Thus, these are considered as the pertinent variables to represent the machinability of a given work material for a given machining operation. The machinability is defined as a machining process variable. It can be any machining process input or output variable. Machinability evaluation can be carried out using both the types of variables. However, as mentioned above, the machining process output variables are the pertinent machinability attributes. In the initial stage, the work materials may be shortlisted on the basis of satisfying the required design and functionality of the product. Machining process input variables, such as work material properties, play an important role in short-listing [4].

After short-listing the materials, the main criterion to choose the work material is its operational performance while being machined, so the focus of decision-making is on the resulting machining process output variables. In manufacturing industries, the basis of machinability evaluation depends on the manufacturers' interests, and many other aspects. For example, some manufacturers consider tool life as the most important criterion to evaluate the machinability, while others consider processed surface finish as the dominant factor. The solution to these difficulties has eluded researchers and practicing engineers for decades. Since there is no universally accepted methodology for evaluating machinability, and numerous new materials enter the market every year, many manufacturers are encountering difficulties in selecting the most appropriate material for their products. So far, research has been mainly based on experimental work to characterize the machinability of work materials.

Some researchers have evaluated the machinability of different work materials, considering any one of the machining process output variable only. Depending on the techno-economic needs of a process, a variable may have a primary or secondary role in the machinability evaluation. However, a realistic estimation of the machinability can be carried out only by considering all the pertinent machining process output variables and their interrelations. The selection procedures suggested by other researchers have considered a number of (i.e. more than one) machining process output variables, with these variables being examined with respect to the work material properties and characteristics. Work materials have been evaluated in terms of their performance with respect to each machining process output variable separately. Then, the final decision regarding selection of work material is made in a subjective manner, in light of the overall performance. It is clear that there is a need to develop a scientific/mathematical tool for machinability evaluation which is capable of considering the requirements of a given machining operation. Work in the direction of the simultaneous consideration of machining process output variables using mathematical models has been reported by a few researchers. However, there is need for a simple, systematic, logical, easy and convenient procedure which affords industry with an efficient and effective means to evaluate the machinability of work materials. This is considered in this paper using a combined multiple attribute decision-making method. **.**

LITERATURE REVIEW

The development of any alloys is an evolutionary process rather than a revolutionary process and aluminum alloys have no exception of this. Many aluminum applications are undergoing a reduction in weight as strength and durability of aluminum is improved by alloying. Research in many areas of aluminum technology, such as advanced alloys, rapid solidification, composites and corrosion resistance, is aimed at keeping aluminum competitive in traditional as well as new applications [9]. Aluminum alloys such as Al-Si, Al-Cu-Si and Al-Mg-Zn alloys are widely used in aerospace and other engineering industries due to their light weight and high strength to weight ratio. The use of conventionally processed Al alloys is sometimes limited by their low strength at temperature above 200^0C .Beyond this temperature; the mechanical properties deteriorate with temperature. Al-TM (TM - transition metal) Systems have the potential for high temperature applications. Among the Al-TM system, Al-Fe-V-Si, Systems have altered considerable interest due to its high strength at room as well as at elevated temperature. Iron is always present in Al alloys. The solid solubility of iron in Al is very low (< 0.04 wt. %) .Therefore most of the iron appears as large intermetallic phases in combination with Al and other elements. Iron reduces the grain size in wrought product [10]. Iron increases the hardness and decreases the ductility. Iron increases corrosion resistance, creep strength and also improves somewhat the machinability of Al.

Al-Si alloys have the potential for excellent cast ability, good weldability, good thermal conductivity, high strength at elevated temperature and excellent corrosion resistance. There are, therefore, well suited for aerospace structural applications, automobile industries, military applications etc.

Grain refinement of the casting yields several benefits. A fine grain size results in mechanical properties that are uniform throughout the material. Also, as the grain size decrease, the distribution of secondary phases and porosity is on a finer scale, and Machinability is improved [11]. Therefore V is added to these alloys for its grain refining effects.

OBJECTIVES AND SCOPE OF THE PRESENT WORK

Al-Fe-V-Si alloys, which has the potential to use in elevated temperature applications. Al-Fe-V-Si alloys are generally produced through rapid solidification process, which exhibit comparable better mechanical properties to conventional cast aluminum alloys. The improved performance of these alloys at elevated temperature have made them strong candidates for a variety of future aerospace applications such as aircraft fuselage, missile fins and winglets, rocket motor cases, and various gas turbine engine components[14]. Al-Fe-V-Si alloys produced through RSP route is also a cost intensive. Sahoo et al. [15, 16] have produced these alloys by melting and casting route.

The entire experimental programme may be grouped under the following heads:-

1. Preparation of Al-Fe-V-Si alloys of different composition.
2. Casting the alloys in various moulds.
3. Determination of mechanical properties of the as cast alloys.
4. Machinability of alloys.
5. Heat treatment of alloys.

Experimental Procedure

The entire experimental work consisted of the following steps:

Alloy Preparation.

Materials calculation for melting
Preparation of alloy

Materials Calculation For Melting

Heat Number 1

Alloy composition: Al-4Fe-1V-1Si
Total weight of charge materials taken for melting = 5 kg.

Si calculation:

Wt. of Si required = (1/100) x5000 = 50 g.
Wt. of Si required including 5% loss = 1.05x50=52.5 g.

V calculation:

Wt. of V required = (1/100) x5000 = 50 g.
Therefore, wt. of Fe-50%V required = 100 g.
Loss is neglected in Fe-V master alloy.

Fe calculation:

Total Fe required (4/100) x5000 = 200 g.
Fe in Al-50%V master alloy = 50 g.
Therefore, additional Fe is required = 200-50 = 150 g.
Because, 21 g Fe present in 100g Master alloy (Al-Fe).
For 150g Fe, required Al-21Fe master alloy = (100/21) x150 = 714 g.
Wt. of Al-21Fe required including 5% loss = 1.05x714=749.7 =750 g.

Al calculation:

Total Al required =(94/100)x5000 = 4700 g = 4.7 kg.
Al present in 714 g Al-21%Fe master alloy = 714-150=564 g.
Therefore, additional Al is required to add in charge = 4700-564=4136 g.
Wt. of Al is required including 5% loss = 1.05x4136 = 4343 g = 4.343 kg.
Thus, the weight quantity of materials
(i) Si = 53 g, (ii) Fe-V = 100 g, (iii) Al-Fe = 750 g, (iv) Al = 4343 g.

Heat Number 5

Alloy composition: Al-5Fe-1V-1Si

Total weight of charge material taken for melting = 3 kg.
The weight quantity of materials:
(i) Si = 31.5 g, (ii) Fe-V = 60 g, (iii) Al-Fe = 600 g, (iv) Al = 2455 g.

Preparation of alloy

The experimental alloys were prepared in an electric heating furnace in a clay bonded graphite crucible under the cover of Na-free flux. First crucible was preheated to about 600^0C. For alloy preparation, Al-21% Fe, Fe-50%V master alloys were used. At around 600^0C, weighted quantity of master alloys, 99.9% pure aluminum and 99.9% pure silicon metallic were charged. (Compositions are given in wt. % unless otherwise mentioned). Just after melting, the molten alloy was covered with a sodium free flux (2% of melt). After melting, sufficient time was given for complete homogenisation of the melt. The melt was frequently agitated with a graphite rod for complete mixing. The cover flux, in the form of scaling and dross etc were skimmed of before the degassing treatment. The melt was then degassed with hexachloroethane. Degasser was wrapped in aluminum foil and plunged into the melt. After degassing the melt was cast in different moulds. The object is to vary the cooling rates.

Pouring of melt at different moulds

After complete homogenization at desired temperature the melt (both modified and unmodified) was poured in different mould to prepare different samples. There were five samples prepared which were poured in (a) 12 mm diameter permanent mould, (b) 12 mm diameter graphite mould, (c) 25 mm thickness permanent (steel) flat mould, (d) 75 mm diameter permanent mould, and (e) copper mould. The pouring temperature was maintained approximately at 880^0C. The fluidity of the melt at this temperature was sufficient for casting test pieces. Cooling curves were also recorded by a strip chart recorder connected to a chromel-alumel thermocouple of 0.4 mm diameter. The thermocouple was placed at the centre of the 25 mm thickness permanent mould. Later on this sample was used for rolling. In all the cases, the mould were preheated approximately up to 150^0C to drive off the moisture**.**

Machinability Test Procedures

Al-Fe-V-Si was machined by using Turning machine. The cutting force was measured by using dynamometer. Machining was carried out with single-point carbide tool in dry environment. Table represents the summaries of experimental condition. Experimental setup for machining of Al-Fe-V-Si.

Details of cutting tool used for experimentation

Cutting Tool- V.N.M.G 12 T 304
Tool Holder- SVJNR 2020K12
Tool Material and Grade – Carbide and IC 907
Rake angle 52^o
Clearance angle 0^o
Cutting edge angle 3^0
Nose radius 0.4

Fig.1: Experimental setup of machining (Turning) of the material.

RESULTS AND DISCUSSION

Mechanical Properties of Alloys

Mechanical properties of both Al-4Fe-1Si-1V and Al-5Fe-1Si-1V alloys are discussed in detail. The hardness of the samples that cast in permanent mould, graphite mould and copper mould are given in the Table 1.

Table1: Vickers's hardness of as cast samples:

Hardness (VHN)				
Alloy	**Permanent mould**	**Graphite mould**	**Copper mould**	
Al-4Fe-1Si-1V	47.2	48.9	46.2	
Al-5Fe-1Si-1V	50.6	49.0	52.0	

From the table, it is clear that hardness is increases as iron content increases. Fig. 9 shows the bar diagram of hardness on the samples that cast in permanent mould of 12mm diameter. Table1show the ultimate tensile strength (UTS), percentage elongation and percentage reduction in area (RA) as cast samples.

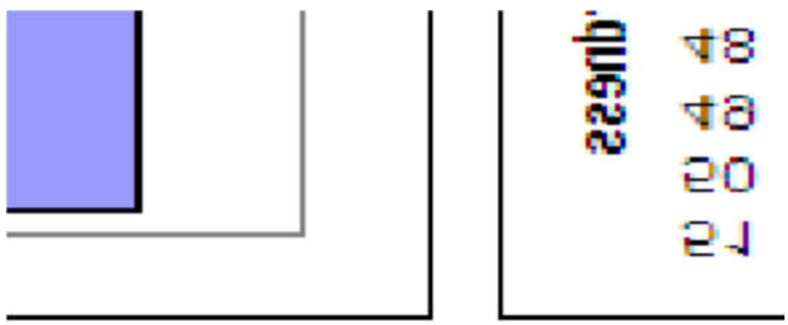

Fig. 2: Hardness of the samples cast in Permanent mould of 12mm dia.

Table2: Mechanical properties of as cast alloys:

Cast alloy	UTS (MPa)	% Elongation	% RA
Al-4Fe-1Si-1V	96	6.5	3
Al-5Fe-1Si-1V	150	3	1

From the table, it is clear that as iron percentage increases, UTS sharply increases but percentage elongation decreases. During tensile testing, cracks are also initiated from the corners of these platelets. Inspite of adequate risering, the cast test pieces of the unmodified alloy show micro shrinkage pores.

The massive iron bearing phases also adversely affect effective feeding in the casting resulting in micro pores. Thus the mechanical properties deteriorate. To avoiding this defect, hot rolling was done and it has been seen that the mechanical properties improve considerably after hot rolling.

Table 3: Mechanical properties of rolled samples

Samples	UTS(MPa)	% elongation
Al-4Fe-1Si-1V (70% reduction)	117	6
Al-4Fe-1Si-1V(80% reduction)	135	5
Al-4Fe-1Si-1V(90% reduction)	122	4

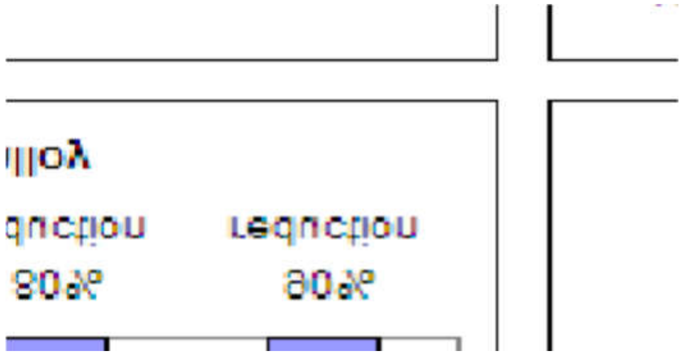

Fig 3: Ultimate Tensile Strength of as-cast and rolled Al-4Fe-1V-1Si alloy

Machinability Test
Chips Formation

Chips formed during the machining (turning) of Al-4Fe-V-Si are shown in fig.3. It has been observed that in first turning at RPM (3000 m/s), Feed (0.2), Depth Of Cut (2.0) there is continuous chip formation and then at same condition it was discontinuous chip formed during machining process. It has been also seen that there is no build of edge found during this process .It means that this alloy is having good machinability at different feed. Tool wear of alloy are very less during turning process, it indicate that machinability is better that of other Al alloys.

Table 4: shows the different Machining Condition

S.No.	RPM	Feed	Depth Of Cut
1	3000	0.2	2.00
2	3500	0.12	1.50
3	4000	0.14	1.00
4	4500	0.16	-50

Surface Finish

The influence of cutting speed on surface roughness characteristics R_a and R_z during turning of Al-Fe-V-Si without use of coolant. The turning operation was performed considering at 0.5 mm/rev constant feed and 0.5 mm depth of cut. The test result shows the value of both surface roughness heights R_a and R_z are low at high cutting speed and comparatively high at low cutting speed. Some times during turning, it can be observed that the average value of surface roughness height (R_z) is low at high cutting speed and comparatively high at low cutting speed. Some times during turning, it can be observed that the value of Average surface roughness height (R_z) is abruptly higher than the trend value.

Table 5: shows the value of Arithmetic average roughness height R_a (µm) and Average Maximum Height of the Profile R_Z(µm) at different cutting speed

S.No.	Cutting Speed(m/min)	Arithmetic average roughness height R_a (µm)	Average Maximum Height of the Profile R_Z (µm)
1	40	.90	5.5
2	60	1.35	6.1
3	80	1.66	6.9
4	100	1.49	5.9

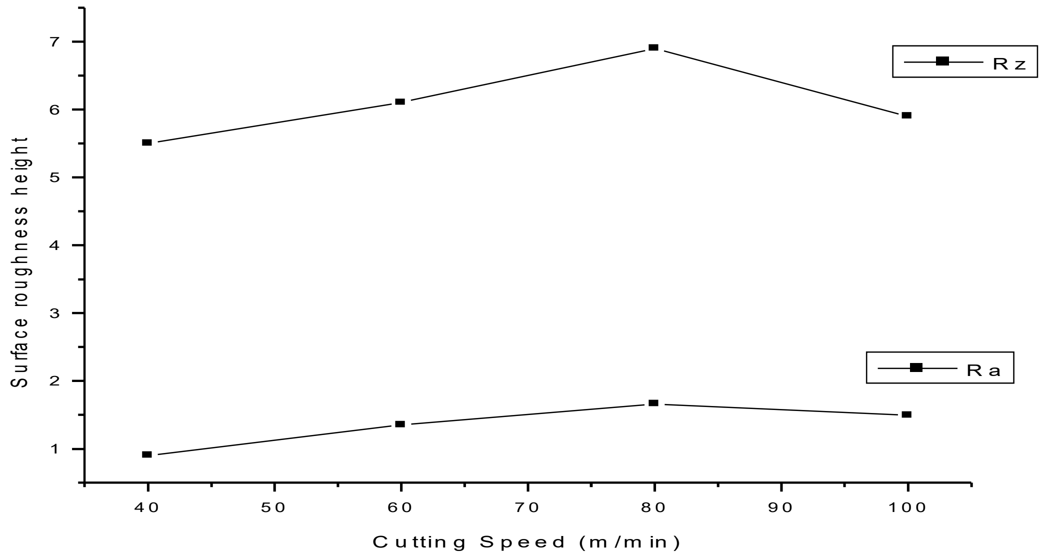

Fig 4: Influence of cutting speed (m/min) on the surface roughness height R_a (µm) and R_Z (µm)

The influence of feed on surface roughness heights R_a and R_Z during machining of Al-Fe-V-Si without use of coolent is also represented in fig 5.5. Experimental Results shows that both the surface roughness heights R_a and R_z increase by increasing feed. Hence it indicates that the cutting speed and feed has equal influence on the surface finish if both are increased simultaneously.

Table 6: shows the value of Arithmetic average roughness height R_a (µm) and Average Maximum Height of the Profile R_Z (µm) at different Feed

S. No.	Feed (mm/rev.)	Arithmetic average roughness height R_a (µm)	Average Maximum Height of the Profile R_Z (µm)
1	0.12	.90	5.5
2	0.14	1.35	6.1
3	.16	1.66	6.9
4	0.2	1.49	5.9

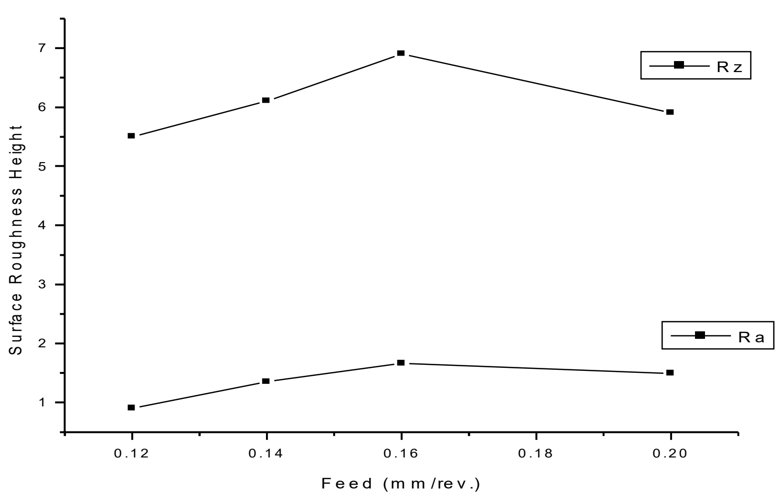

Fig. 5: Influence of feed (mm/rev.) on the surface roughness height R_a (µm) and R_Z (µm)

The influence of depth of cut on surface roughness height R_a and R_Z during machining of Al-Fe-V-Si. Without use of coolent is represented by fig 4.5.
Table 5.6 show the value of Arithmetic average roughness height R_a (µm) and Average Maximum Height of the Profile R_Z (µm) at different Depth of cut

CONCLUSION

- Hardness is increases as iron content increases from 4 to 5 %
- As iron % increases, UTS sharply increases but % elongation decreases.
- The mechanical properties of the alloy are improved through hot rolling of the cast samples. 80% reduction gives the best ultimate tensile strength.
- Hardness is almost constant at 250˚C up to 230 hours.
- From the experiments it has been seen that these alloys is having good machinability.
- As Depth of cut and Feed rate increases, cutting force is required more but with increase of cutting speed, cutting force decreases.
- At different Cutting speed, Depth of Cut and Feed, it produces Discontinuous chips.
- On increasing of Depth of Cut, roughness of surface increases during machining.

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