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CAIRO - EGYPT

WORK HARDENING IN TURNING OF AL-10%WT CU ALLOY PRODUCED BY RHEOCASTING

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ABSTRACT

The present paper gives some results on the work hardening obtained during turning of Al-10% Cu alloy produced by rheocasting and conventional casting techniques. The machinability of this alloy is shortly discussed. A simple procedure was adopted to turn cylindrical workpieces on a centre lathe to investigate the effect of the feed and the depth of cut on the work hardening of such an alloy. Microhardness was measured across specimens, thus determining the depth of the work hardened zone in the vicinty of the periphery. Results show that the depth of the work hardened layer in the rheocast specimens was less than that of the conventionally cast specimens indicating better machinability of the former. This behaviour is related to the microstructure formed by each casting technique. The relatively hard spheres of primary phase embedded in a highly fine two phase harder matrix present in the rheocast specimens is thought to be responsible for the smaller depth of the work hardened zone.

INTRODUCTION

During the last decade, a lot of research work has been directed towards the improvement of alloy properties in the as-cast condition by applying some inovative casting processes |1|. One of the processes which shows remarkable improvement in soundness, homogeneity and structure of the alloy is the so called rheocasting (R.C.) or stir-casting process. This technique has been started on a scientific base by Flemings et al |2| in 1972. The process is still considered now by other research groups mainly in Delft University, Netherland |3|, in Foundry Institute, Achen, West Germany |4| and more extensively in Ain Shams University, Cairo |5|.

The technique comprises stirring while solidification of the alloy then pouring it at a temperature between the liquidus and solidus. A structure is developed in which nearly spherical primary particles exist in a fine dendritic matrix, Great improvement in the homogeneity and soundness was observed |6,7,8,9 and 10|. A remarkable improvement in the mechanical properties of several alloys was achieved by using this technique. The ten-

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sile strength and ductility could almost be doubled while the compressive strength reaches 7 to 10 times those values obtained by conventional casting technique |5,7,12|. In addition, there are indications showing improvement of the formability in the semi-solid state |10,11|.

However, there is a great lack of information about other properties of the R.C. material. One of the important properties is its machinability. The machining characteristics of an alloy is determined by its composition, microstructure, bulk strength, hardness and work hardenability |12|. Aluminum alloys differ from many other alloys in that its machinability improves as strength and hardness increase |12|. The casting process affects the alloy solidification rate and microstructure and consequently its machining characteristics. The coarser sand cast microstructure due to slower solidification rate tends to a lower strength and is generally related to poorer machinability. Die casting tends to have a different interior surface composition and structure due to higher solidification rates. Therefore, better machining characteristics than sand casting are obtained |12|.

Since the rheocasting alloy shows promising behaviour in many aspects, a study on its machining characteristics will give new useful technological data. Generally, machinability has no single measure in the literature so that no accurate and quantitative measure could be found. In the present work, the depth of the work hardened zone will be considered as an indirect measure of machinability.

It is well known that aluminum alloys have high machinability and that Al-Cu alloys are one of the best machinable alloys. Therefore, Al-10%wt Cu alloy has been choosen for the present investigation, especially that its rheocasting properties have been previously studied in details |8,10,13|.

EXPERIMENTAL PROCEDURE

Al-10wt% Cu alloy was prepared under a protective argon atmosphere from aluminum of commercial purity (99.8%) and high purity electrolytic copper. The details of producing Al-10wt% Cu alloy using the rheocasting technique has been published elsewhere |8,13|.

Rods of 10 mm diameter and 100 mm length have been produced with smooth surface by suction from the stirred slurry (stiring speed = 482 r.p.m.) at a temperature within the mushy zone (878 K) in alumina tubes followed by rapid quenching in water. For the purpose of comparison, another group of workpieces was prepared by suction of the superheated melt (10 K above liquidus) in alumina tube and then quenched in water. This group represents the conventional cast (C.C.) workpieces.

Samples of the two groups were turned on a centre lathe using a HSS tool. Two cutting parameters were varied to study their effect on the depth of the work hardened zone. These two parameters are the depth of cut and the feed. Table (1) shows the values of these two cutting parameters during experimental tests.

The cutting speed was kept constant at 22 m/min. When studying the effect of the depth of cut, the feed was kept constant at 0.16 mm/rev, while during the study of the feed effect, depth of cut was constant at 1 mm.

Table (1)
Feeds and depthes of cut used in experimental tests

Depth of cut (mm)	0.25	0.50	1.25	1.50
Feed (mm/rev)	0.08	0.16	0.65	1.04

After turning, cross-sectional specimens were cut then cold-mounted and polished for both microscopic observation and microhardness testing. Microhardness tests were conducted using a load of 100 gf and a loading time of 5 seconds on a SHIMADZU microhardness Vickers tester. The indentations were 10 μm apart. The results were taken as the average of three specimens.

RESULTS AND DISCUSSION

The phase diagram of the Al-Cu system shows that at temperatures below 820 K, the microstructure of the Al-10wt% Cu alloy consists of primary Al-Cu solid solution (α) embedded in a eutectic matrix containing the hard $CuAl_2$ intermetallic phase. The conditions at which these phases are present significantly affect the mechanical and deformation behaviour of the alloy |14|. On the present work, the C.C. specimens are obtained by directly quenching the superheated liquid into water at 300 K. As a result, a high cooling rate was given to the sample which was 10 mm in diameter. The resulting microstructure consists of a small volume fraction of primary α embedded in a fine eutectic matrix which can be clearly seen in Fig. (1).

The R.C. specimens, as they are quenched after stirring at a temperature below the liquidus, have a different microstructure. Fig. (2) shows primary coarse - almost rounded - α particles embedded in a fine two-phase (α dendrites + eutectic) matrix which is finer than that of C.C. specimens. The copper concentration in the primary phase is expected to be different in C.C. and R.C. specimens. As the R.C. specimens are quenched at a lower temperature, the primary α phase is expected to contain more copper in solid solution. This is supported by microhardness measurements. The hardness of the primary α phase reaches a value of 71 and 83 VHN for C.C. and R.C. specimens respectively.

The microhardness of the primary α phase was measured across the diameter of the samples after turning at a constant speed of 22 m/min and feed of 0.6 mm/rev while the depth of cut was varied. The results plotted in Figs. (3) to (6) show that the hardness reaches a maximum value at the periphery. This value drops gradually with distance from the periphery until a constant value is reached. This behaviour is similar for both R.C. and C.C. specimens. However, the maximum hardness values and the depth of the hardened layer δ are different in each case. It is to be noted that the hardness values of the R.C. specimens are always higher than those of the C.C. specimens.

The depth of the hardened layer, estimated from Figs. (3) to (6), is plotted versus the depth of cut and is shown in Fig. (7). The figure shows that δ increases as the depth of cut increases for both R.C. and C.C. specimens and that the values of δ are higher for the C.C. specimens. As the starting value of the hardness of the R.C. α phase is higher than that of the C.C. α phase, more resistance to deformation of the former takes place which results in the thinner hardened layer. Moreover, the

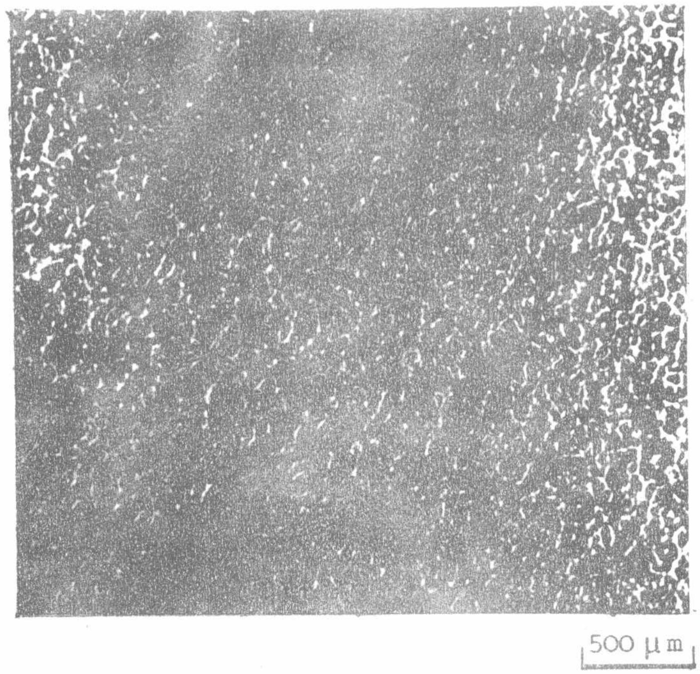

Fig. (1) Typical microstructure of C.C. Al-10wt% Cu alloy cast 10K above liquidus, then directly water quenched.

Fig. (2) Typical microstructure of R.C. Al-10wt% Cu alloy, cast from 878K (between liquidus and solidus), then directly quenched in water. (Applied stirring speed=482 r.p.m.

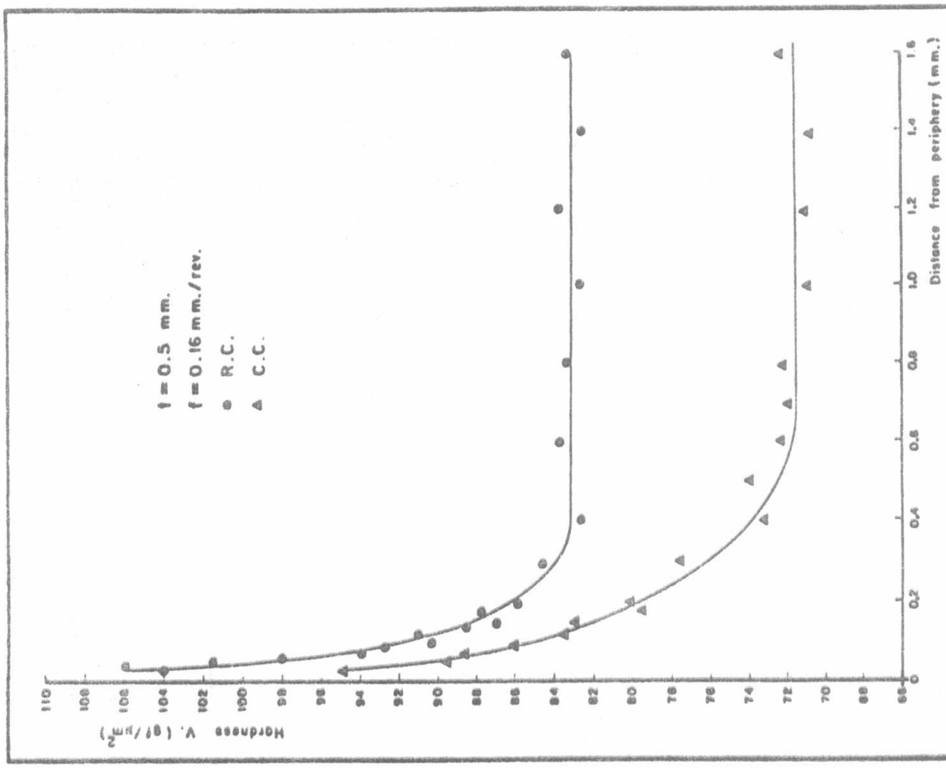

Fig. (4) Variation of hardness with depth of work hardened layer (depth of cut = 0.5 mm., feed=0.16 mm./rev.)

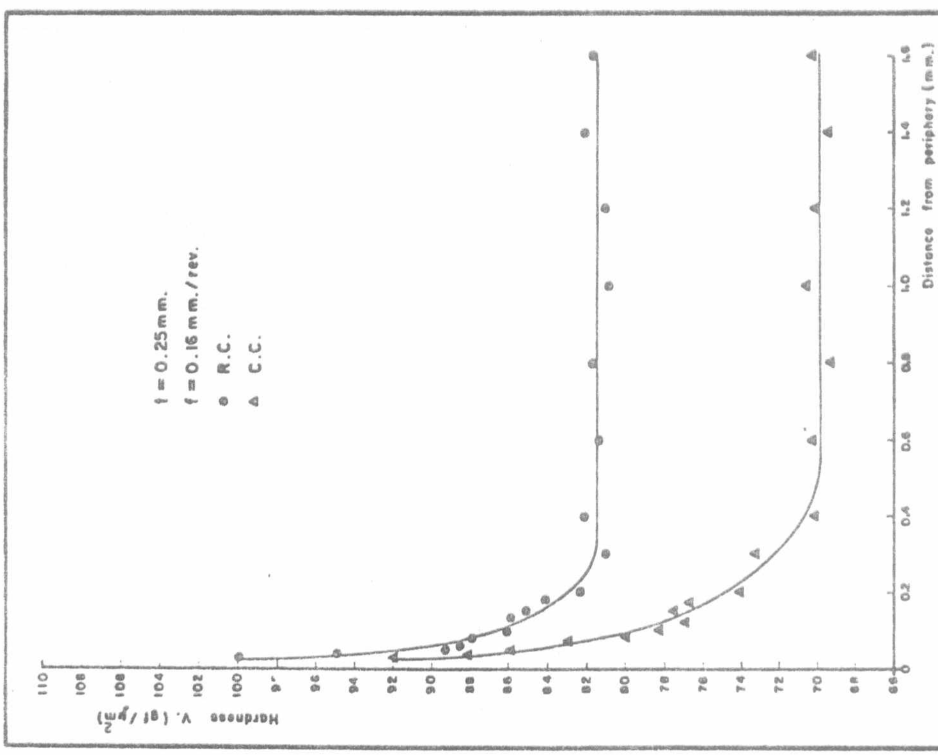

Fig. (3) Variation of hardness with depth of work hardened layer (depth of cut = 0.25 mm., feed= 0.16 mm./rev.)

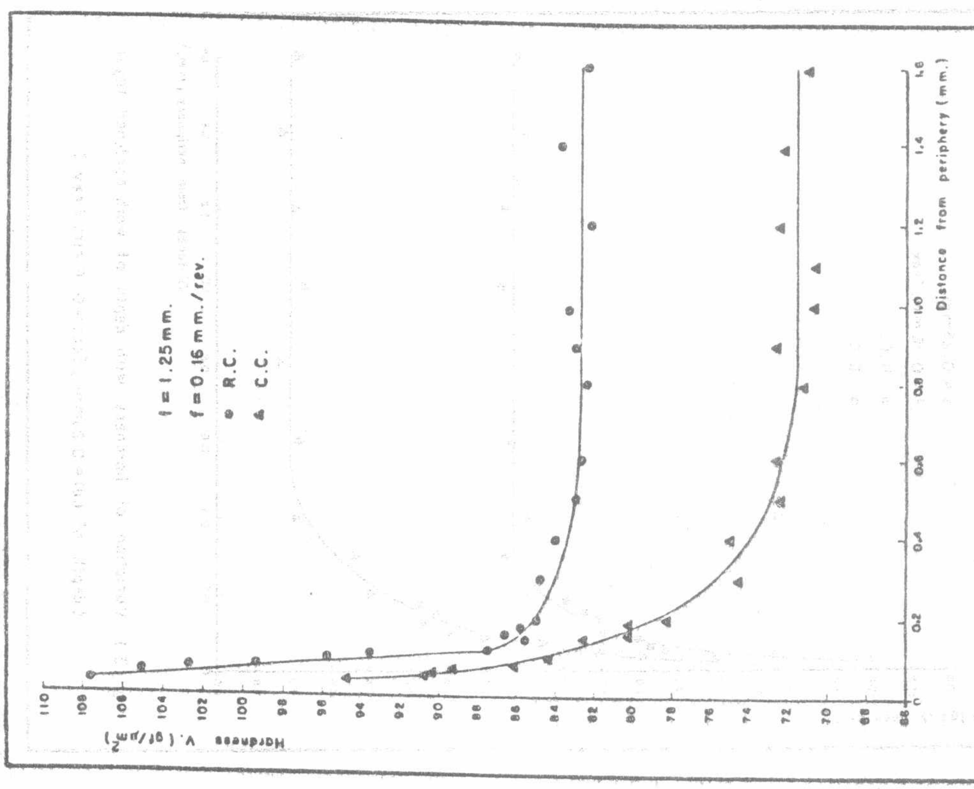

Fig. (5) Variation of hardness with depth of work hardened layer
(depth of cut = 1.25 mm., feed = 0.16 mm./rev.)

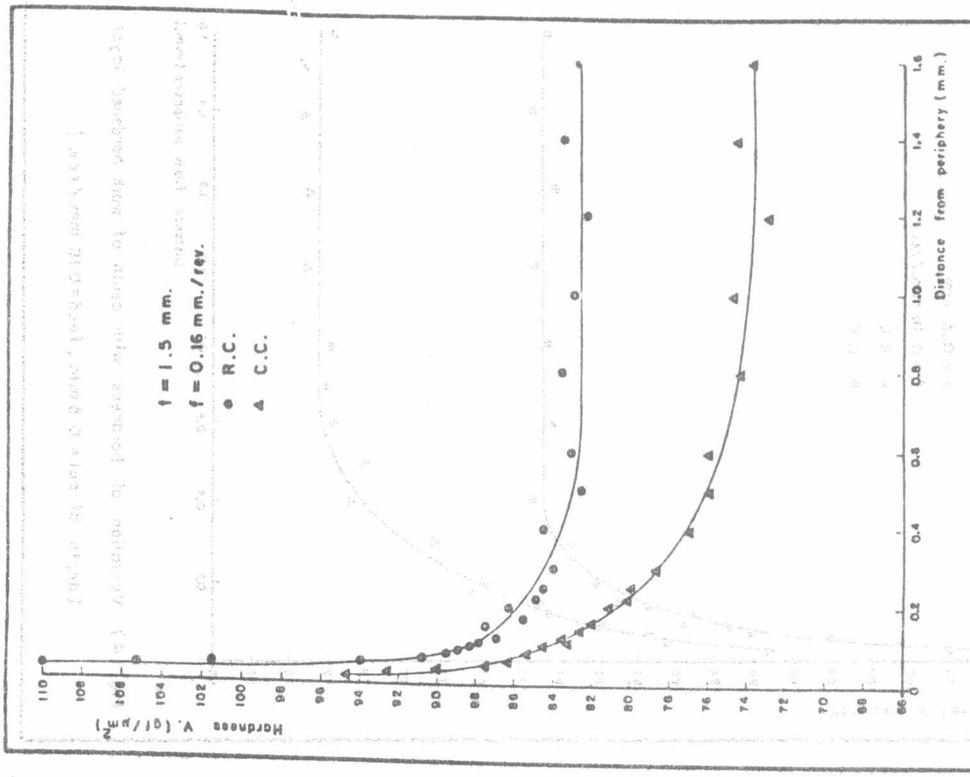

Fig. (6) Variation of hardness with depth of work hardened layer
(depth of cut = 1.5 mm., feed = 0.16 mm./rev.)

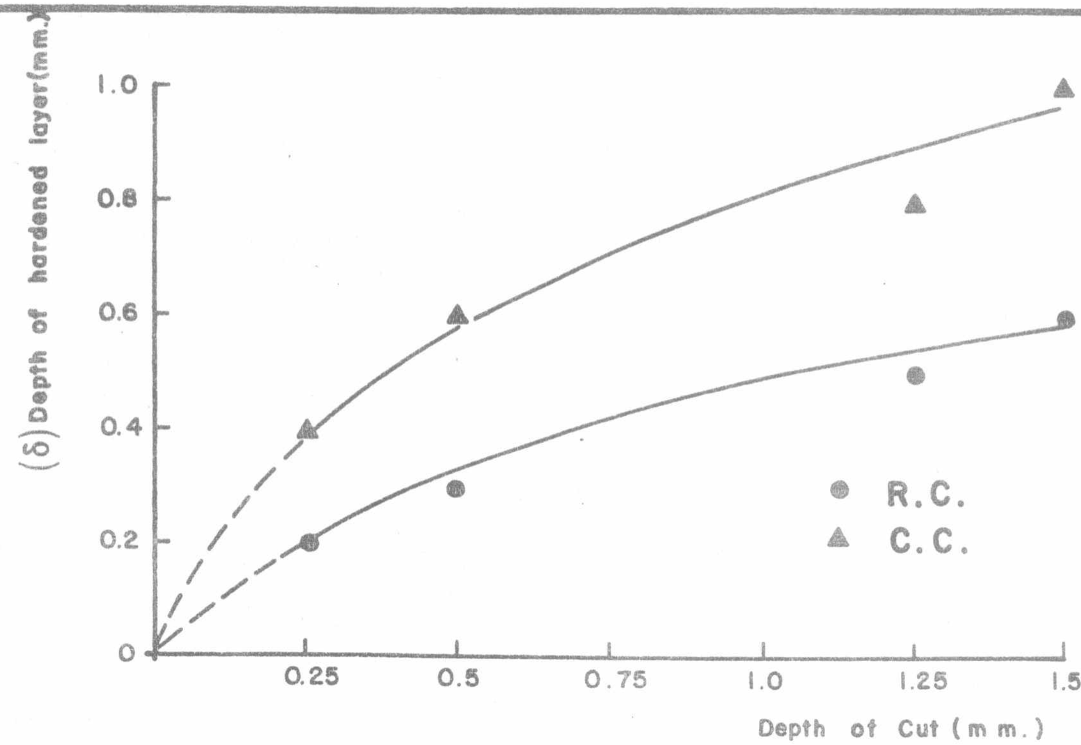

Fig. (7) Effect of depth of cut on depth of work hardened layer.

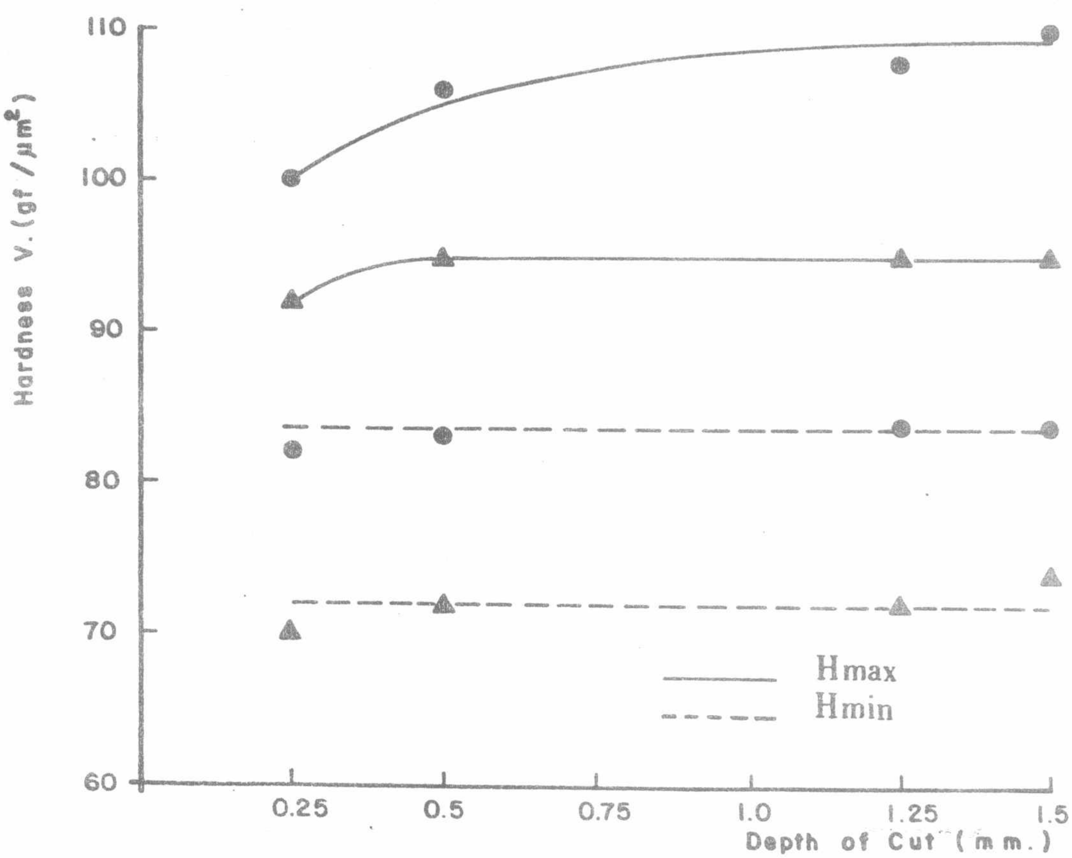

Fig. (8) Variation of maximum & minimum hardness with depth of cut.

matrix of the R.C. material has a finer structure compared to that of the C.C. material. The finer structure gives a better distribution of the hard intermetallic phase which helps improving the machinability of the same alloy. This is illustrated by comparing the machinability of Al-Si alloys cast in sand for both modified and unmodified structure |12|. In the fine well modified structure, the hard Si phase is finely distributed which improves the machinability of the alloy to a great extent by distroying its abrasive effect on the tool |12|.

It is to be noted that measurements of microstructural parameters and hardness across R.C. specimens give uniform values in the present work as well as in previous work |8,13|, thus leading to uniform machinability across the section. Similar measurements across C.C. specimens show that a finer structure is obtained at the periphery, which is related to higher cooling rate, while a coarser structure is found in the core due to slower cooling rate. This again affects the machinability in a sense that the periphery gives better results than the corein C.C. specimens. This is to be observed if a large amount of metal is removed especially in sand castings.

The effect of feed on the depth of the work hardened layer δ has also been investigated. The results show a scatter in the depth of the hardened layer so that no definite trend was observed. Further studies are needed to deeply investigate the effect of the feed and tool geometry.

Aluminum alloys are usually soft and the formation of the built-up edge is therefore a reason for several problems in cutting operations. In a recent study on the characteristics of Al-Si-Cu (380) die cast alloy, it was found that the built-up edge was affected dramatically by the matrix hardness of the workpiece alloy and perhaps by its work hardening |15|. Zinc was found to improve the machinability of aluminum castings as it hardens the matrix and makes a lubricating effect |16|. The presence of small amounts of Pb, Bi, or Sn in aluminum improves the degree of natural lubrication |17|.

CONCLUSION

From the previous results and observations, it may be concluded that the machinability could be improved by rheocasting. This is based on the relatively soft primary phase (lubricating effect) embedded in a harder matrix with fine uniform structure and with absence of coarse intermetallic phases. On the other hand, the primary phase has a relatively high hardness compared to that of pure aluminum and therefore a lower ductility, thus almost preventing the formation of the built-up edge during cutting. However, more experimental work is needed in order to completely evaluate the improvement of machinability obtained in R.C. alloys.

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