STUDIES ON THE NATURE OF SURFACE QUALITY IN PRECISION GRINDING OF CARBON STEELS

Reddy, K.H.Prasad, Nair, P.Kesavan, Ramamoorthy, B.
Indian Institute of Technology, Madras, INDIA.
E-mail: hariprasadreddy@hotmail.com

INTRODUCTION

Grinding is one of the most versatile methods of removing material from machine parts to provide precise geometry. In addition to dimensional control, the objectives in precision grinding of any component include satisfaction of surface quality or surface integrity requirements. In grinding operation, randomly distributed abrasive particles of various geometrical forms, varying in their cutting characteristics induce plastic deformation, thermal damage and consequent macro and micro residual stresses. The present work is a systematic study of the influence of grinding parameters on the surface quality (macro and micro residual stresses, phase transformations) of ground finished components.

EXPERIMENTAL DETAILS

For the present study, medium carbon steel (0.4%C) specimens of diameter 30mm and thickness of 8 mm were used. All the samples were normalized at 900^0C for 2 hours to maintain a uniform initial state. Horizontal spindle reciprocating table surface grinding machine was selected for the present study. Traverse grinding was carried out with different grinding conditions. Grinding conditions were selected as per Taguchi's L8 orthogonal array with different grinding parameters at different levels by considering the high and low practical limits as indicated in Table 1.

Trial No.	Depth of cut (μm)	Wheel Speed (m/sec)	Cross feed (mm)	Dressing speed (mm/min)	Coolant condition
1	5	15.4	0.01	200	Dry
2	5	30.9	0.1	700	Wet
3	10	15.4	0.01	700	Wet
4	10	30.9	0.1	200	Dry
5	20	15.4	0.1	200	Wet
6	20	30.9	0.01	700	Dry
7	40	15.4	0.1	700	Dry
8	40	30.9	0.01	200	Wet

Table 1: Orthogonal array of grinding parameters

During grinding, spark temperature at the wheel-workpiece contact zone was measured with the help of infrared radiation pyrometer by focussing very close tot he wheel-workpiece contact zone. Surface finish was measured using perthometer. Residual stresses were estimated using multiple exposure X-ray diffraction technique employing Rigaku stress analyzer in directions parallel and perpendicular to the lay. Micro strain values were determined using the X-ray line profile analysis by double line integral breadth method. Phase analysis was carried out with X-ray diffractometer using Fe-Kα radiation. Results are analyzed and the most influencing parameter on the macro and micro residual stresses was determined with ANOVA analysis.

RESULTS AND DISCUSSION

As the depth of cut, wheel speed and cross feed increases more thermal damage will be induced on the workpiece due to increase in the wheel-workpiece contact zone temperature. In the case of fine dressing condition free cutting is not possible and it introduces more thermal damage on the surface of the work piece. In the case of dry grinding, the temperature that is developed in the grinding zone is very high compared to the wet grinding. The surface roughness and temperature values are indicted in Table 2.

Trial No.	1	2	3	4	5	6	7	8
Surface Roughness, R_a (μm)	0.43	0.62	0.66	0.95	0.73	0.44	1.49	0.35
Temperature (^{0}C)	< 400	500	400	850	500	700	750	500

Table 2. Surface Roughness and Temperature results as per Experimental Trials.

The temperature and Surface roughness values are high in the case of trial 4 and trial 7 compared to other trials. In the case of trial 4 this is due to the cumulative effect of high wheel speed, high cross feed, fine dressing condition and dry grinding. In the case of trial 7 due to high depth of cut, high cross feed and dry grinding the temperature and surface finish are having high values. From the ANOVA analysis of the observed temperature and surface finish values, cross feed, depth of cut and coolant have major influence on the temperature and surface finish. Dressing speed is the least significant factor, which has about 7% contribution on the observed values.

Figure 1 shows the variation of macro residual stress and micro strain with depth of cut estimated through Taguchi techniques. In the grinding process, the induced residual stresses arise due to three different mechanisms, viz. mechanical effects, thermal effects and transformational effects. During grinding, the contact zone can be considered as a strip heat source, that moving in the cutting direction which induces thermal damage. The residual stresses induced purely due to this thermal effect will be highly tensile in the direction of motion of the heat source (i.e. parallel to the lay) and somewhat less in the direction perpendicular to the lay. The purely mechanical effects on the other hand will introduce compressive residual stresses. The absolute magnitudes of these stresses depend up on the extent of plastic deformation. The transformational effect if present, on the other hand will introduce a highly compressive stress due to the volumetric expansion involved originating through crystallographic reasons. The resultant stresses will be an algebraic sum of the stresses due to these three effects. At low depth of cut (5μm), the influence of thermal effect is negligible as the observed temperature is very less and mechanical effect is the only factor, which introduces the residual stresses. This could be the reason for compressive nature of the residual stress at this condition. At 10μm depth of cut, the thermal effects are fairly high and the result is increase in the residual stress value. Further increase in depth of cut, increases the influence of mechanical effect. The observed temperature values showed that the influence of thermal effects is less than the previous one. Hence, the result is decrease in the residual stress. At 40μm depth of cut, due to increase in thermal effects the induced residual stresses also increased. As far as the micro residual stresses are concerned as the depth of cut increases, recovery/recrystallization effects bring down the micro strain values. The change in the peak position and breadth of the ferrite phase from the X-ray phase diffractograms provides the information for change in the microstrain values. Figure 2 shows the variation of residual stresses and micro strain as a function of cross feed. At low cross feed the contact zone temperature is less (~500^{0}C) compared to that of high cross feed (650^{0}C). Hence, at high cross feed the thermal effects influence is high and induces more tensile residual stresses. More over, the effect of increasing the cross feed is to reduce the reheating effect of the already machined region. This implies that as the cross feed increases the thermal annealing effects become less, i.e. an increase in both macro and micro residual stresses could be expected. Figure 3 shows the variation of residual stresses and microstrain as a function of wheel speed. As the cutting speed increases, the specific grinding energy required to remove the material will increase. The thermal damage at high wheel speed is more than that of low wheel speed. These factors contribute to increase in the residual stress values as the wheel speed increases. Similar to the depth of cut condition, recovery/recrystallization effects bring down the micro strain values other wise microstrain has to increase with increase in wheel speed. Figure 4 indicates the variation of residual stresses and microstrain with coolant condition. Grinding with coolant reduces the thermal damage and reduces the forces that are developed during grinding. This could be the reason for the reduction in the residual stress values while grinding with coolant. In the fine dressed wheel condition (dressing speed: 200mm/min), the structure of the wheel will be closed grain structure and results in wheel surfaces that are not free cutting which leads to an increased thermal impact. This induces tensile residual stresses although the surface quality is improved in many cases. This can be the reason for the reduction in the residual stresses as the dressing speed increases. As the present study is based on the traverse grinding, the influence of dressing speed is very less. In the present analysis, the wheel-workpiece contact zone didn’t cross the A3 line of the iron-ironcarbide diagram. Hence, the influence of transformational effects were not present The thermal damage and the plastic deformation which takes place during grinding has more influence in the direction parallel to the lay compared to that of perpendicular to the lay. This can be the reason for less residual stress values in the direction perpendicular to the lay in all the cases. The ANOVA analysis results showed that the major influencing parameter in controlling the macro residual stress is cross feed (~60%) and depth of cut (~30 %). Depth of cut (49%) and wheel speed (42%) has more influence on the microstrain than other grinding parameters.

CONCLUSIONS

During the grinding process, in the direction perpendicular to the lay high compressive residual stresses are induced when compared to that parallel to the lay. As the grinding conditions become severe (high depth of cut, wheel speed and cross feed, low dressing speed and dry grinding), the magnitude of residual stresses increases unless there is no transformational effect. The origin of induced microstrain and macro residual stresses is different from each other. The major influencing parameters on the induced macro residual stress is cross feed and depth of cut. The major influencing parameters on the induced microstrain is depth of cut and wheel speed. Dressing speed has very little influence on the induced macro residual stress and microstrain in traverse grinding. There is not much change in the existing phases due to grinding.

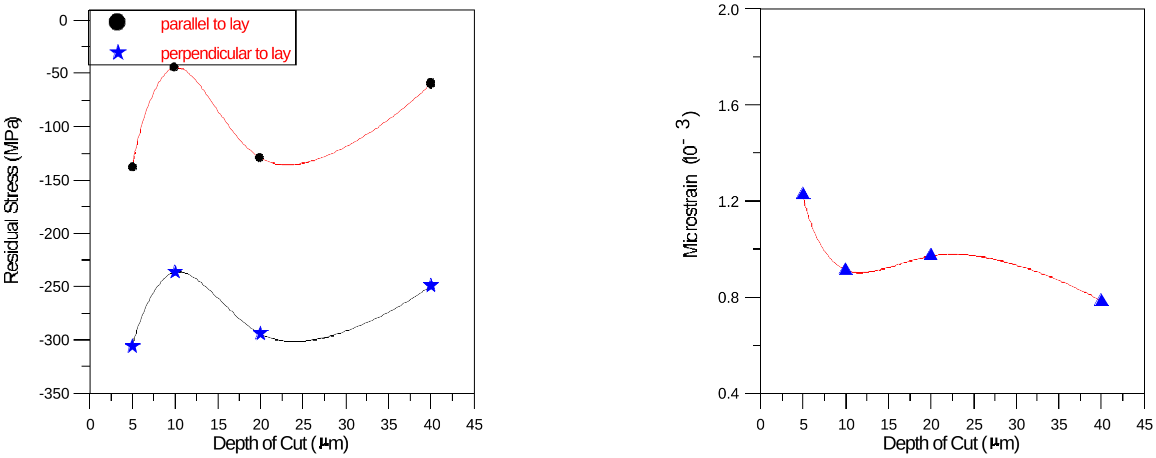

Fig. 1 Variation of macro residual stress and microstrain with depth of cut

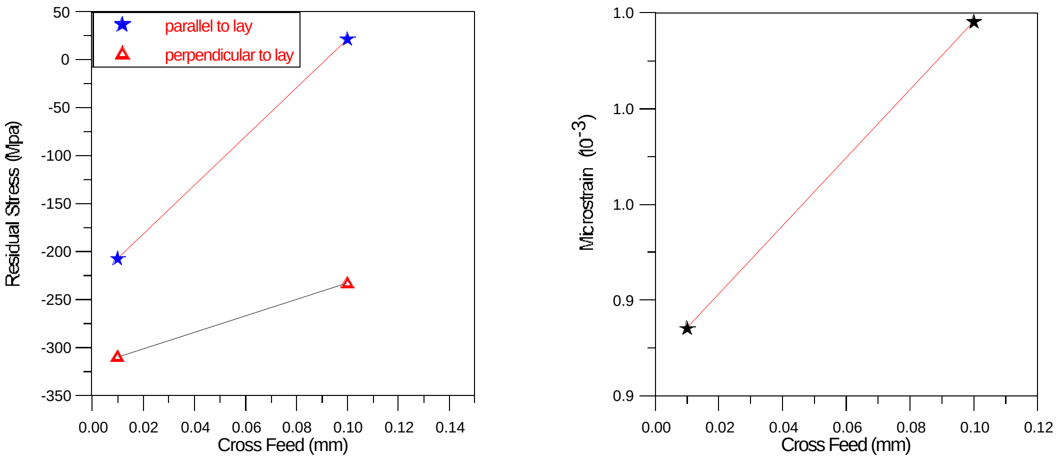

Fig:2 Variation of macro residual stress and microstrain with cross feed

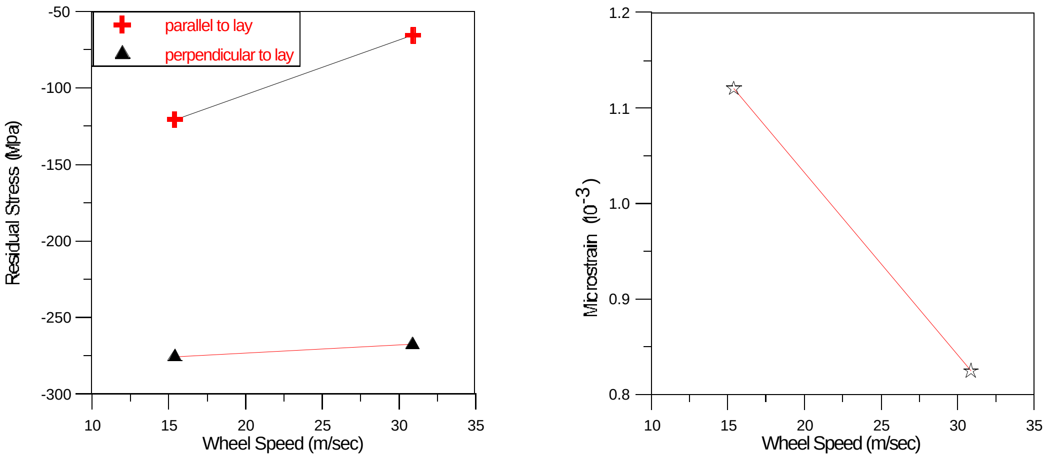

Fig:3 Variation of macro residual stress and microstrain with wheel speed

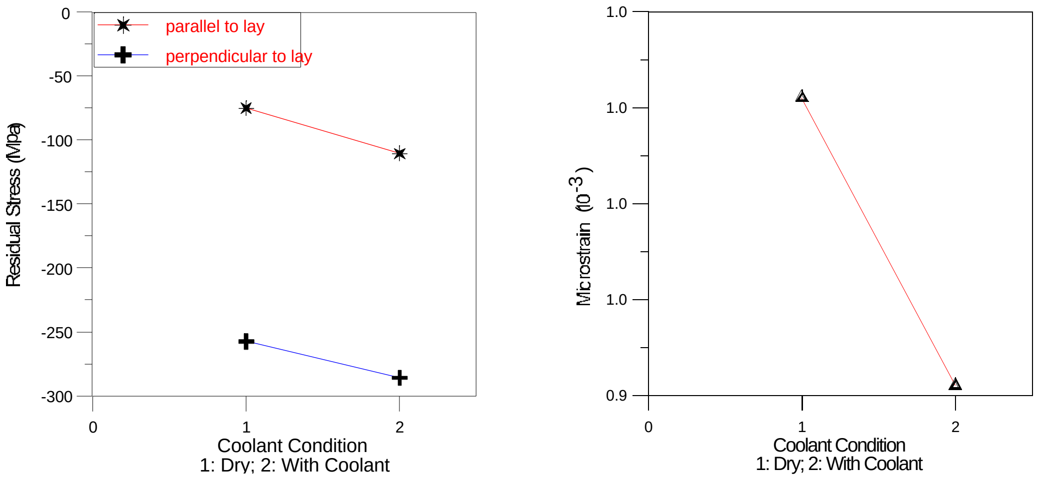

Fig. 4 Variation of macro residual stress and microstrain with coolant condition