Chapter 7

Conclusions

7.1 Conclusions

A great deal of work was done to develop an efficient and reliable finite element method for analyzing the residual stresses induced by grinding in relation to grinding parameters and workmaterial properties. Investigations carried out in the present thesis include

(i) thermal steady state and transient analyses of the grinding process based on both constant and variable workmaterial properties,

(ii) the correlation of critical grinding conditions with the onset of the irreversible deformation of the workpiece due to plastic deformation and phase transformation,

(iii) the martensite zone beyond the critical grinding temperature history,

(iv) residual stresses introduced by pure mechanical surface traction under iso-thermal grinding conditions,

(v) thermal residual stresses with phase change,

(vi) thermo-mechanical residual stresses under constant workmaterial properties when the maximum grinding temperature is below the austenizing temperature and

(vii) full coupling of thermal-plastic deformation, mechanical-plastic deformation and irreversible deformation by phase transformation.

To carry out the above analyses, with moving traction and heat flux associated with grinding, a user-supplied material model (CUSER2, CUSERH and USERSL) has been built up. For problems with constant workmaterial properties, the steady state model provided by ADINA was employed indirectly. For those with temperature-dependent properties, a transient model was used. Phase transformation and the associated workmaterial properties change was taken into account by building up an elastic-plastic user subroutine(CUSER2). Special codes developed include:

(1) the change of thermal and mechanical properties of workmaterial and

(2) the change of boundary conditions associated with thermal and mechanical loading movements across the workpiece surface subjected to grinding.

The investigation led to the following new findings and conclusions:

(1) Up-grinding with l_a =0.25 is the most critical grinding condition for constant workmaterial properties since it yields a higher martensite depth,

(2) With the coupling of phase transformation and thermo-plasticity

(i) surface hardening and volume growth due to phase transformation dominate the transition of residual stresses from compressive to tensile,

(ii) residual stresses in the no-martensite zone are nearly unaffected by surface hardening and volume change and

(iii) the maximum surface residual stress is sensitive to cooling when the convection coefficient is below a certain value and is a weak function of the strength of heat flux when the strength is beyond a critical level;

(3) With the coupling of thermal and mechanical grinding conditions but with a low heat flux intensity

(i) normal mechanical traction and the 'friction' factor have a critical role in changing the nature of residual stresses,

(ii) an up-grinding operation is safer in terms of residual stress distribution provided that a lower 'friction' factor and a smaller input heat flux intensity are sustained,

(iii) if the maximum grinding temperature is kept the same and a low input heat flux intensity is maintained, the surface tensile residual stresses can be reduced when a higher cooling rate is imposed by either increasing the table speed of grinding or by enlarging the convection heat transfer coefficient of the coolant and

(iv) if a low heat flux cannot be sustained, a down-grinding process should be employed to reduce surface residual stresses.

(4) Under a pure mechanical surface traction,

(i) residual stress distribution is sensitive to the profile of the traction within the grinding zone, and

(ii) the following grinding conditions are recommended to generate compressive surface residual stresses;

(a) using a down-grinding operation,

(b)

the material studied), and

(c) employing a smaller depth of cut to maintain the average normal stress level below a critical value associated with collapse deformation.

(5) With fully coupled thermal-plastic deformation, mechanical-plastic deformation and irreversible deformation by phase change,

(i) surface hardening associated with phase change will slightly increase if cooling power is increased,

(ii) the influence of mechanical grinding conditions on residual stress distribution becomes minor, and therefore,

(iii) surface hardening becomes the dominant factor in determining residual stress distribution.

(6) The distribution and the onset of residual stresses are very sensitive to mechanical and thermal loading profiles under discrete grinding forces. A lower active area of cutting can yield larger residual stresses if the grinding forces are kept the same. Thus the sharpness of the grinding wheel and the size of the active cutting grits are the dominant factors in determining the residual stress levels. However, the detailed interaction between a grinding wheel and a workpiece needs to be considered carefully to obtain a more realistic prediction of residual stresses.

7.2 Suggestions for Further Study

It is clear that the assumptions regarding the interaction between a workpiece and a grinding wheel need to be refined in the light of non-linear contact mechanisms including material removal and heat generation. The current assumption of moving traction has a number of disadvantages because the residual stress predictions are sensitive to the traction profile and intensity. A further development in this regard is therefore important.

The most difficult non-linearity in simulating a grinding process is that with material separation. The general relation between stress and strain must therefore include the onset of workmaterial removal and chip formation. However, as pointed out by Zhang (1998), none of the existing separation criteria is reliable. Hence further studies must aim to accomplish the following:

1. To establish realistic modelling of the grinding wheel and the workpiece engagements by proper representation of the contact phenomenon between the grinding wheel grits and the workpiece materials.

2. To find suitable criteria for a workmaterial removal mechanism by experimental investigations and to correlate the experimental evidence with the associated computational predictions.

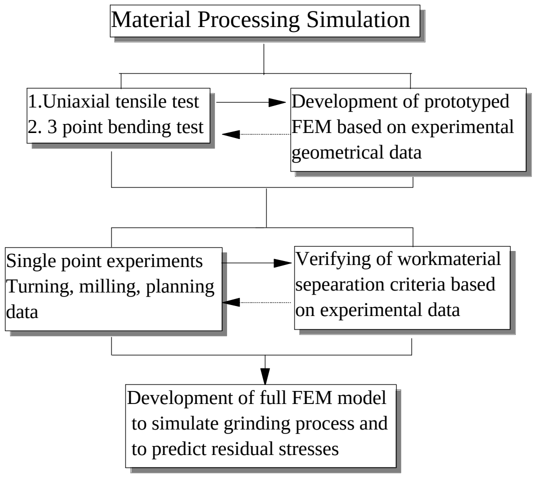

Fig.7.1 Process modelling strategies

3. To develop an effective and powerful finite element method (FEM) for grinding process modelling and the determination of the associated residual stresses in ground components. The suggested future plan to build up the required FEM can be summarized in Fig. 7.1

It should be noted that the above suggestions for further study regarding modelling work may not be enough unless some critical experimental work are conducted to verify the outcome of the numerical investigations. To achieve this, the following experimental work should be performed simultaneously: (1) temperature measurements in the workpiece during grinding; (2) observation of plastic deformation using SEM and TEM; (3) determination of phase transformation; and (4) direct measurement of residual stresses using XRD.