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The R_t of Analysis Model under the Adiabatic Shear Mechanism

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***Abstract*—A-T model of the modified hydrodynamics, is widely used in metal projectile and target materials, good prediction accuracy for penetration depth in penetration process. But the R_t (target defense force) is determined relatively difficult, lack of real physical meaning to widely accepted the R_t of calculation model. Based on the role of the existence of adiabatic shear failure mechanism between projectile and target, the R_t is endowed with real physical meaning, It can be better reflected the failure mechanism of target plate for influence of the thermal effect and strain rate in penetration. Theoretical model calculation is carried out under the R_t of new mechanism, The results are in good agreement with the experimental and simulation results.**

Keywords—A-T model; penetration; adiabatic shear; failure mechanism

I. Introduction

Based on Bernoullequation,Tate[1] and Alekseevskii[2] is separately proposed the modified hydrodynamics one-dimensional model (A-T model), and gain widely acceptance and extended application, its basic expression for $1/2\,\rho_p(v-u)^2+Y_p=1/2\,\rho_t u^2+R_t$, the concept dynamic yield strength of projectile and target defense force is first put forward. The model recognized projectile material have rigid plastic constitution relationship. The material is in a fluid state only in the small area of the contact interface between the projectile and target. Ignored the transition from rigid body to fluid in projectile area. By A-T model combined with no deformation of the projectile velocity attenuation equation, projectile body erosion equation, the relationship between the penetration depth and penetration speed that penetration depth can be obtained. of be in English, also the table and figure texts, otherwise we cannot publish your paper. How to determine the Y_p and the R_t of the model is the core issue for predict the penetration depth. Tate[3] is found the Y_p and the R_t to be the same order of magnitude as the elastic limit of Hugoniot for projectile and target materials, and the R_t times of the target plate material yield strength.

II. The Introduction of Common R_t Models

Model 1: elastic-plastic, compressible material model, the expression of Hill[4] is

$$R_t=2/3Y_t\left[1+\ln\left(E_t/3Y_t(1-\upsilon)\right)\right] \tag{1}$$

Among them Y_t, E_t, υ areseparately for of material dynamic yield strength and elastic modulus, poisson's ratio.

Model 2: elastic-plastic,incompressible material model,the expression of Tate[5] is

$$R_t=Y_t\left[2/3+\ln\left(2E_t/3Y\right)\right] \tag{2}$$

The the parameter meaning of formula(2) are same meaning in formula (1).

Model 3: elastic-plastic,incompressible materialmodel ,the expression of Satapathy[6] is

$$R_t=-2/3Y_t\ln\left(Y_t/2G_t\right)+2/3Y_t \tag{3}$$

Among them, G_t is shear modulus of the target plate.

For the 603 homogenous armor steel material studied in this paper, Y_t, E_t, G_t, υ is respectively 1.13Gpa, 210Gpa, 12.8Gpa, 0.22, the values calculated by model 1, model 2 and model 3 are 4.05GPa, 6.21GPa and 3.12GPa respectively. The same material with different model, R_t value of the differences in values vary greatly, and then it will affect the calculation accuracy of penetration depth.Therefore, the article will combine adiabatic shear mechanism defined to R_t new definition in the penetration.

III. The Definition of R_t Combination by Adiabatic Shear Mechanism

A. Analysis of the Mechanism of Adiabatic Shear Penetration

Through cavity expansion theoretical method, although target defense force can be obtained through material yield strength, modulus of elasticity or shear modulus. But, if we want to get the ideal accuracy of penetration depth calculation, it is also necessary to make some corrections to the value from the experimental result. The value of the traditional meaning R_t, the difference of values calculated by different models is obvious, so that the calculated results of penetration depth are poor in consistency. In addition, it can not reflect the adiabatic shearing phenomenon commonly existing in high-speed penetration. The thermal effect and the effect of high strain rate on the penetration process are also discussed.

The formation of adiabatic shear band (ASB) has an important influence on the armor piercing mechanism. The material damage at the mesoscopic level generally includes: micro holes, micro cracks and shear bands, under the effect of the impact load. Adiabatic shear bands are accompanied by heterogeneous mesoscopic deformation of materials. This deformation will produce micro cracks and microspores under subsequent action, even the initiation and expansion of the crack. Macroscopically, the action area of the projectile and target is combined with the superposition of high shear stress and flowing static stress, shear instability, cause the breakage of the material of the target plate.

Figure I show the high-speed impact of a projectile on a target is actually a process of deformation and failure at high strain rates.Conversion of most plastic deformation work into heat, and the heat generated is too late to spread out, in a narrow area. The temperature in the narrow band rises sharply in a very short time, the heat softening of the target plate in this area, at the same time, the strain hardening effect of the material is also accompanied by the process.Before adiabatic shear occurs, the strain hardening effect of the material is dominant,strain and strain rate increase with the deformation time, when the strain increases to the critical strain, moreover, thermal softening in the narrow-band region is beyond the strain hardening effect, collapse of stress layer, thus the adiabatic shear band is formed.

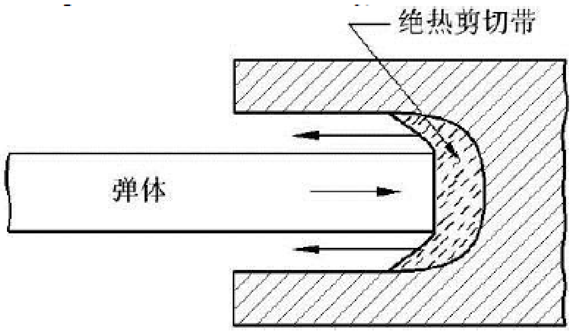

FIGURE I. FAILURE SCHEMATIC DIAGRAM OF ADIABATIC SHEAR BAND IN PENETRATION

Figure II to Figure III, the edge morphology of the 93 tungsten alloy projectile and the pit wall is observed at meso and macro scale respectively.The adiabatic shear band is obviously visible, shows that the target plate was experiencing adiabatic shear failure in the process of crushing flow. From the above analysis, when the thermal softening effect of the target material exceeds the strain hardening effect, the material was in the state of softening flow, adiabatic shear occurred. The area of the projectile and target area considered in the A-T model, the condition that the projectile overcomes the defense force of target plate to form the flow state is consistent. Therefore, the critical shear stress value τ_c of adiabatic shear failure is given R_t.

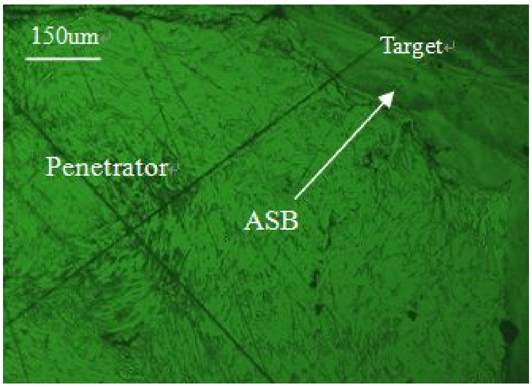

FIGURE II. MESOSCOPIC SEM PHOTO OF THE ADIABATIC SHEAR BAND

FIGURE III. MACROSCOPIC ADIABATIC SHEAR BAND

B. Quantitative Description of Adiabatic Shear

Recht[7]quantitatively described the causes of adiabatic shear bands in 1974. He expressed the problem as follows:

$$\tau = f(T, \gamma) \tag{4}$$

$$\mathrm{d}\tau = (\partial\tau/\partial T)\,\mathrm{d}T + (\partial\tau/\partial\gamma)\,\mathrm{d}\gamma \tag{5}$$

$$\mathrm{d}\tau/\mathrm{d}\gamma = (\partial\tau/\partial T)(\partial T/\partial\gamma) + \partial\tau/\partial\gamma \quad (6)$$

τ is the shear stress of the material, T is the temperature of the material.

He believed that the conditions for the adiabatic shear bands formed is

$$\mathrm{d}\tau/\mathrm{d}T \le 0 \quad \mathrm{d}\tau/\mathrm{d}\gamma = -(\partial\tau/\partial T)(\partial T/\partial\gamma) \quad (7)$$

The significance of formula (7) reflects the balance between plastic hardening and thermal softening during instability.

On the basis of Recht, strain rate $\dot{\gamma}$ dependence is introduced, the increment of shear stress is obtained.

$$\mathrm{d}\tau = (\partial\tau/\partial T)\mathrm{d}T + (\partial\tau/\partial\gamma)\mathrm{d}\gamma + (\partial\tau/\partial\dot{\gamma})\mathrm{d}\dot{\gamma} \quad (8)$$

The constitutive relation in adiabatic shear band is derived.

$$\tau = (\tau_0 + h\gamma)e^{\frac{-\alpha\eta\gamma}{2\rho c}(2\tau_0 + h\gamma)} \quad (9)$$

Among them: ρ is the density of materials, c is the specific heat of materials, and η is the thermal conversion coefficient. τ_0 is the shear ratio limit of the static load, h is the strain hardening factor,and α is the thermal softening coefficient.When $\mathrm{d}\tau/\mathrm{d}\gamma = 0$, the critical shear strain that produces an adiabatic shear band is obtained.

$$\gamma_c = 1/h\left(\sqrt{h\rho c/\eta\alpha} - \tau_0\right) \quad (10)$$

And the relationship between temperature and strain

$$T = \frac{1}{\alpha}\left(1 - e^{\frac{-\alpha\eta\gamma}{2\rho c}(2\tau_0 + h\gamma)}\right) \quad (11)$$

As shown in Figure IV and Figure V, (For the 603 homogenous armour steel material, material parameters $\rho_t = 7.85\times10^3$ kg/m^3, $C = 460$ J/kg, $\eta = 0.9$), the strain hardening coefficient h values are related to temperature, but the degree of influence is weak. When taking T=15°C, $h = 0.2G_t$, $\alpha = 1/1000$, the above parameters are brought into the formula (10).Available $\gamma_c = 0.53$, $\tau_c = 4.48$GPa.

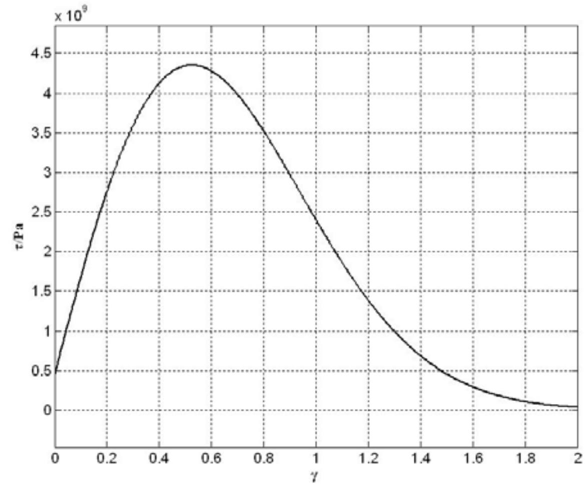

FIGURE IV. THE SHEAR STRESS VARIATION CURVE OF WITH STRAIN

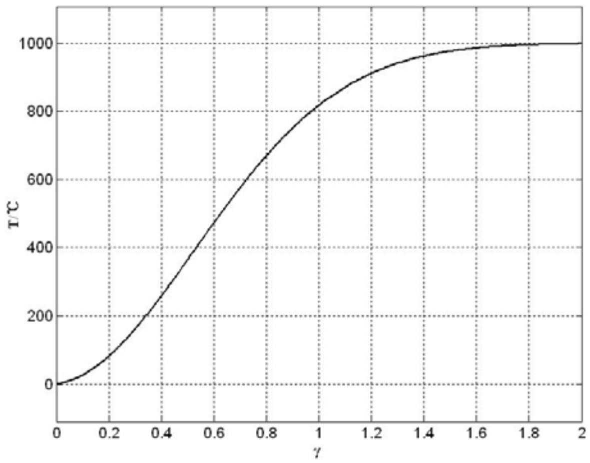

FIGURE V. THE TEMPERATURE VARIATION CURVE WITH THE SHEAR STRESS

The critical temperature($T_c = 398.2$ °C) of adabatic shear band can be obtained by introducing $\gamma_c = 0.53$ to formula (11).It can be seen from this when the shear stress exceeds 4.48GPa, the shear strain exceeds 0.53, and the temperature exceeds 398.2°C,adiabatic shear failure will occur in the process of penetration,for the 603 homogenous armour steel material.

As shown in Figure VI, the penetration depth error calculated by the A - T model is not more than 3.9% for the test value, and the error between the theoretical calculation values and the numerical values is not more than 5.5%. It has good consistency with the two.

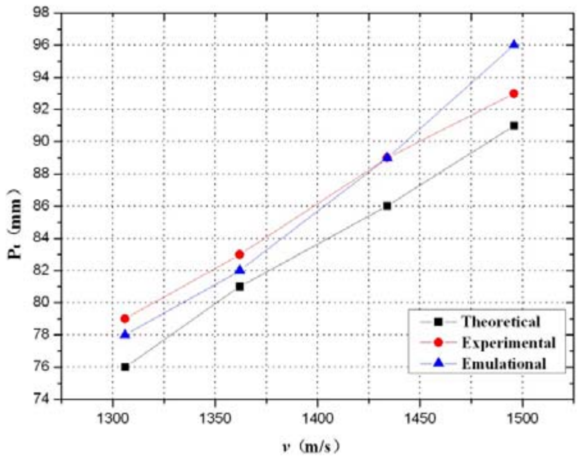

FIGURE VI. THE PENETRATION DEPTHVARIATION WITH IMPACT SPEED

IV. SUMMARY

The theory of cavity expansion is a common method to determine the R_t of the target plate. Because of the different selection of material constitutive relation and failure criterion of metal target plate, the R_t model derived is not the same, and the difference of calculation results is very obvious. In this paper, based on the mechanism analysis of the penetration process, based on the adiabatic shear failure mechanism of the target plate material, the critical shear stress value of the adiabatic shear failure of the target plate material which has more practical physical significance is given to R_t, and the more ideal results are obtained.

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