3D Numerical Simulation and Analysis of Railgun Gouging Mechanism

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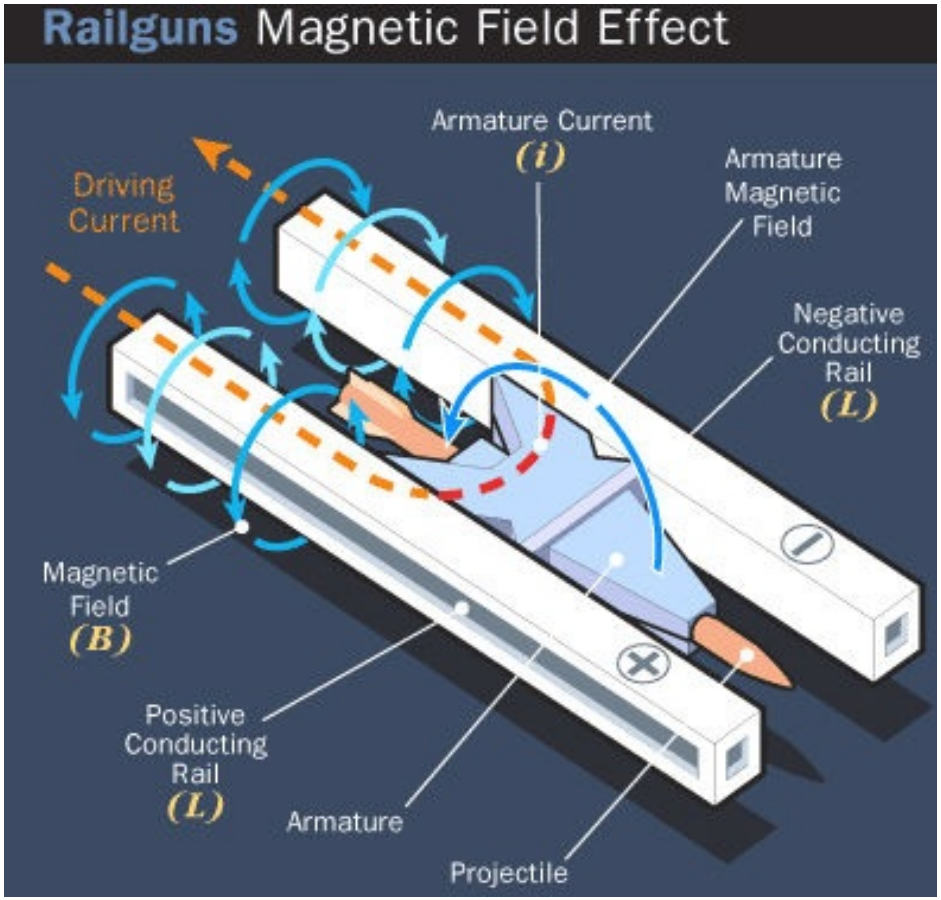
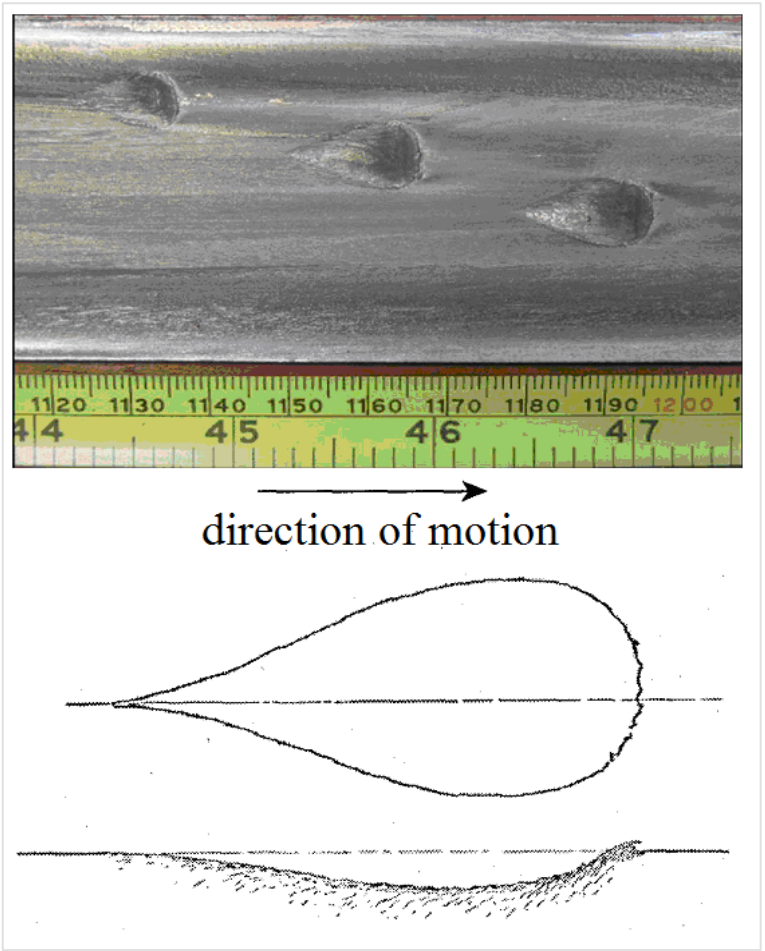
1 What's Railgun Gouging ?

Schematic of a railgun



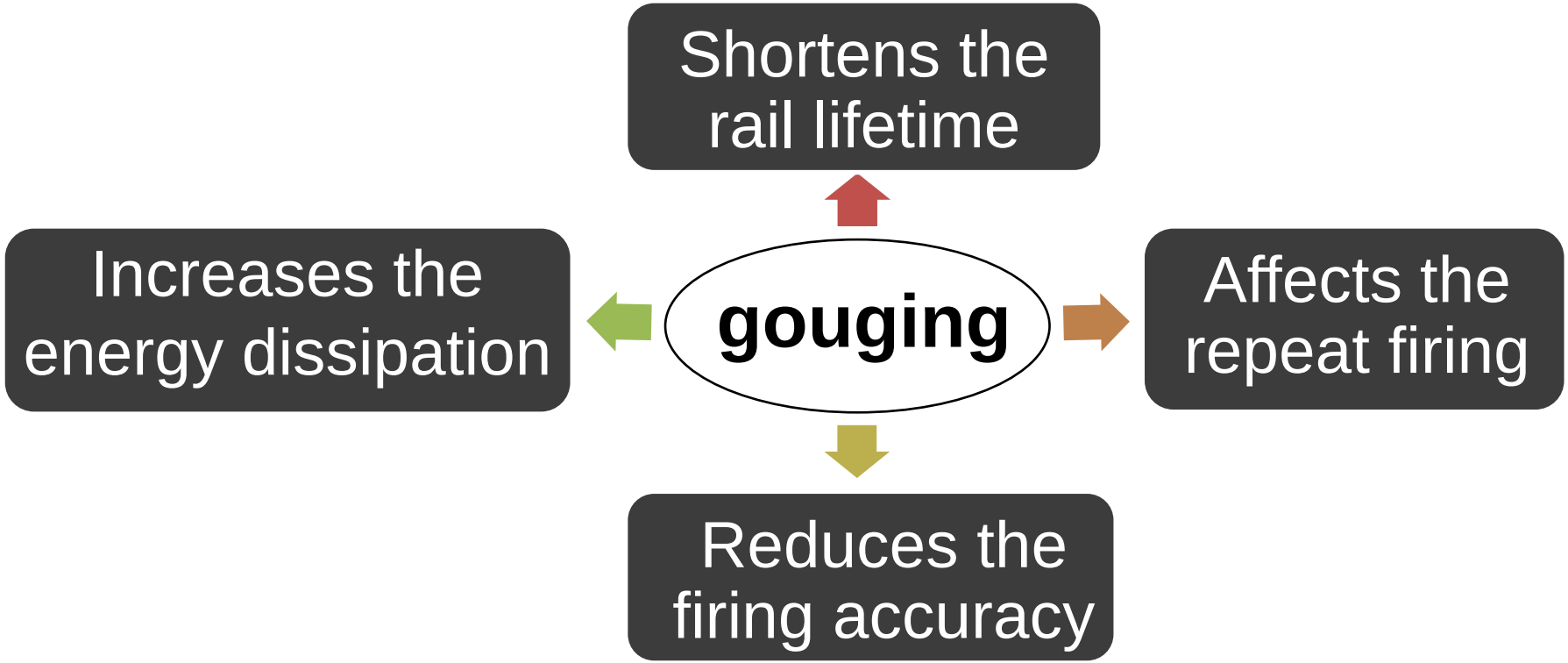
Gouging in railgun experiments



Features: the teardrop shape ; severe plastic deformation ; materials mixing

1 What's Railgun Gouging ?

Main hazards



1 What's Railgun Gouging ?

Generation Mechanism

Railgun gouging mechanism
(*impact thermal dynamics*)

- micro impact at hypervelocity ($10^1 \sim 10^2$ μs)
  - parallel impact (micro defects; rail bulge)
  - normal impact (gap; vibration)
- heat effects
  - plastic deformation heating
  - friction heating
  - Joule heating

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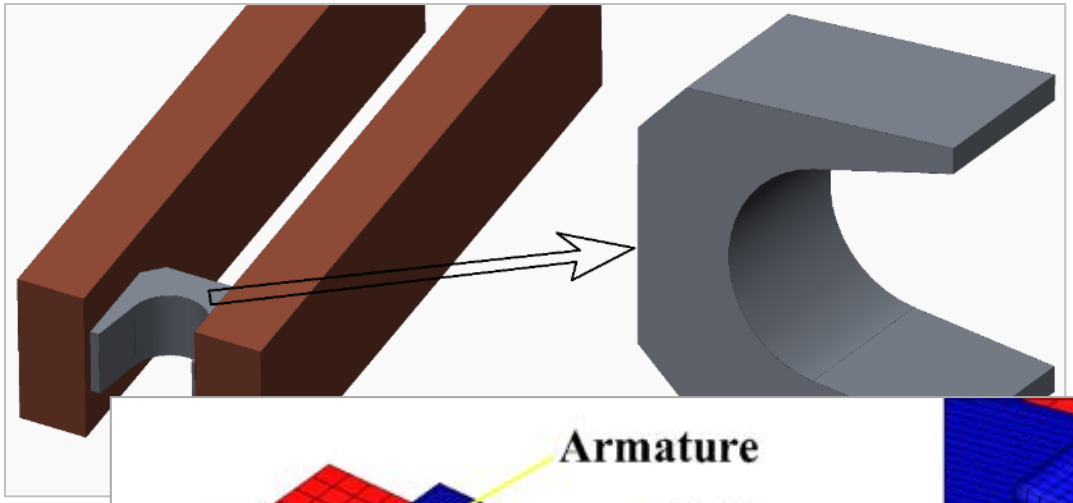
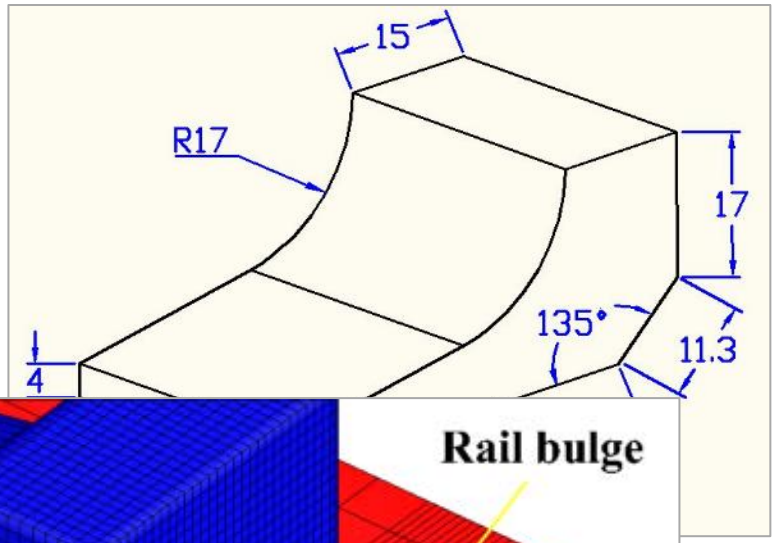
2 the Construction of a Simulation Model

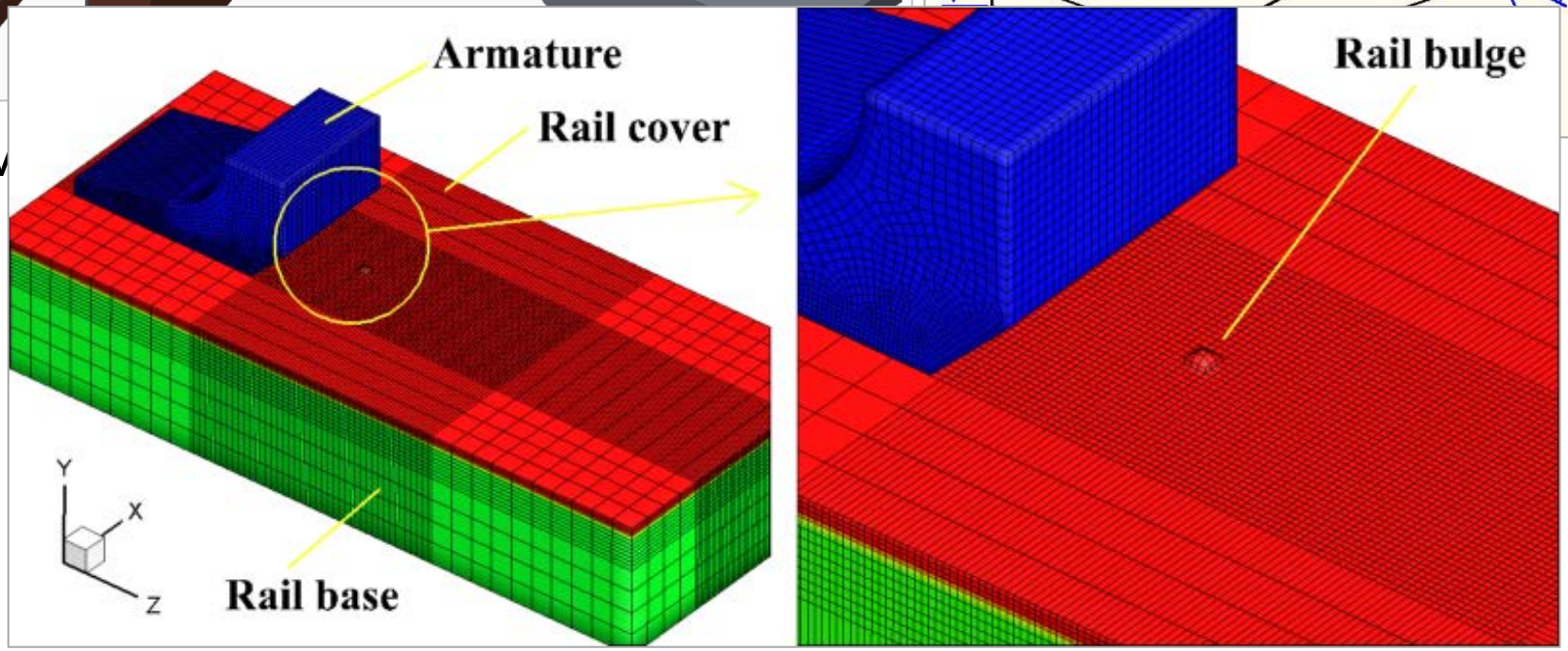
Design model



Armature sizes



FEM



2 the Construction of a Simulation Model

Dynamic constitutive model

Johnson-cook model:

$$\sigma_y = \left[A + B(\varepsilon^p)^n\right](1 + C\ln\frac{\dot{\varepsilon}^p}{\dot{\varepsilon}_0})\left[1 - T^{*m}\right]$$

where $T^* = (T - T_r)/(T_m - T_r)$

$\dot{\varepsilon}^p$: effective plastic strain rate;

$\dot{\varepsilon}_0$: referential strain rate;

T_r : referential temperature;

T_m : material's melting temperature.

The strain at fracture:

$$\varepsilon_f^p = (D_1 + D_2 e^{D_3\sigma^*})(1 + D_4\ln\frac{\dot{\varepsilon}^p}{\dot{\varepsilon}_0})(1 + D_5 T^*)$$

where $\sigma^* = \sigma_m / \sigma_{eq}$

Damage parameter : $D = \sum \frac{\Delta\varepsilon^p}{\varepsilon_f^p}$

Temperature rise from plastic strain:

$$\Delta T = \int_0^{\varepsilon_p} \frac{\chi\sigma_{eq}}{\rho c_p} d\varepsilon_p$$

where σ_{eq} : effective stress;

χ : the ratio plastic work to heat;

Mie-Grüneisen equation of state:

$$p = \begin{cases} \dfrac{\rho_0 c_0^2 \mu[1 + (1 - \frac{\gamma_0}{2})\mu]}{[1 - (s-1)\mu]^2} + \gamma_0\rho_0 e \ , & \mu \geq 0 \\ \rho_0 c_0^2 \mu + \gamma_0\rho_0 e \ , & \mu < 0 \end{cases}$$

2 the Construction of a Simulation Model

Material parameters

Armature - 7075 Al; Rail - OFHC Copper

Table 1 material parameters of armature and rail

Parameter	7075 Al	OFHC Cu	Parameter	7075 Al	OFHC Cu	Parameter	7075 Al	OFHC Cu
ρ /(kg·m^{-3})	2810	8960	C	0.0083	0.025	D_2	0.13	4.0
E /GPa	71	124	m	1.7	1.09	D_3	-1.5	2.0
v	0.33	0.34	T_m /K	933	1356	D_4	0.011	0.014
c_p /(J·kg^{-1}·K^{-1})	960	383	T_r /K	293	293	D_5	0	1.12
A /MPa	369	90	$\dot{\varepsilon}_0$ /s^{-1}	1.0	1.0	c_0 /(m·s^{-1})	5350	3940
B /MPa	684	292	χ	0.9	0.9	s	1.34	1.49
n	0.73	0.31	D_1	0.13	0.54	γ_0	2.0	2.0

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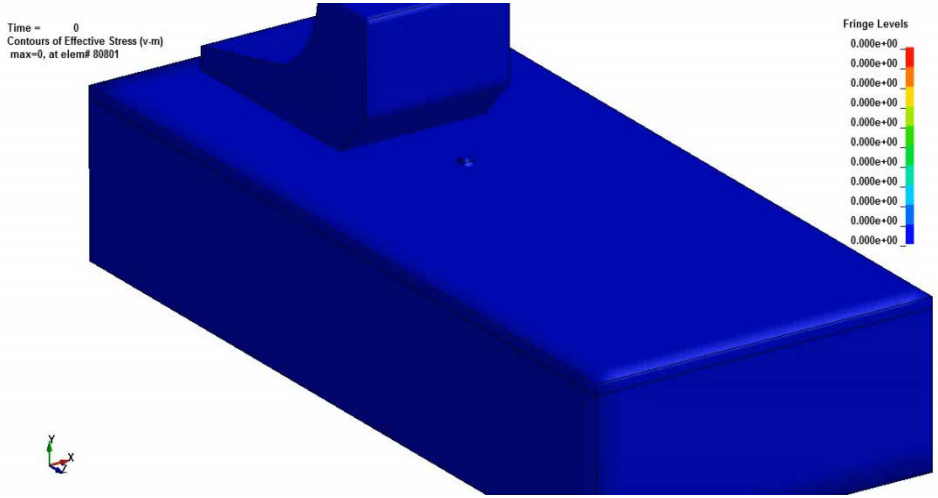
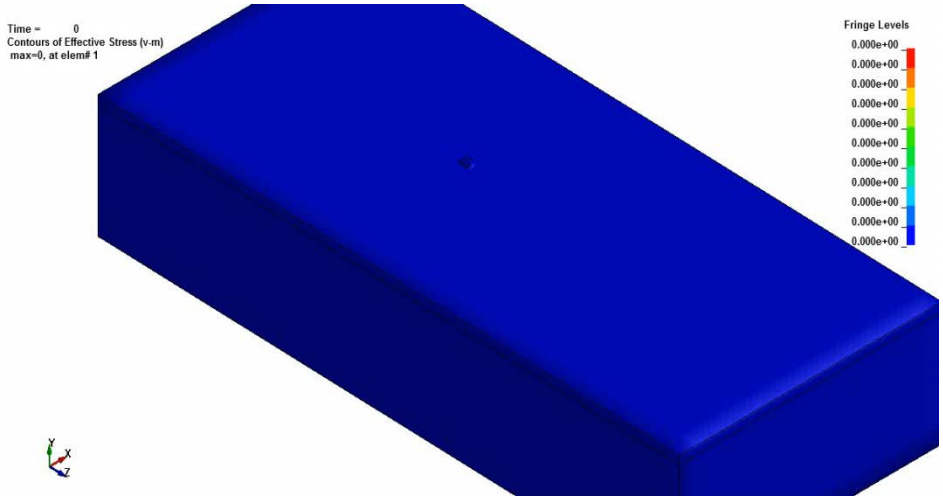
3 Results and Discussions

Contours of Effective Stress :



Velocity : 2000 m/s



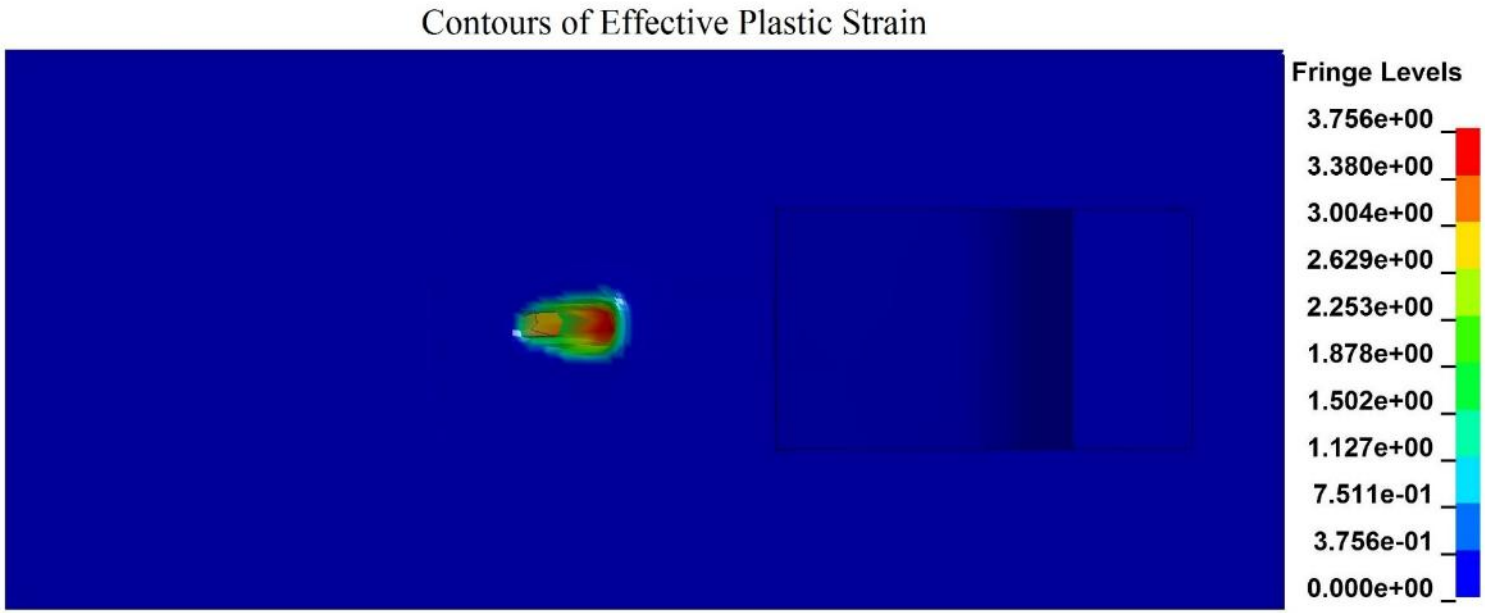
Contours of Plastic Strain :

Velocity : 2000 m/s

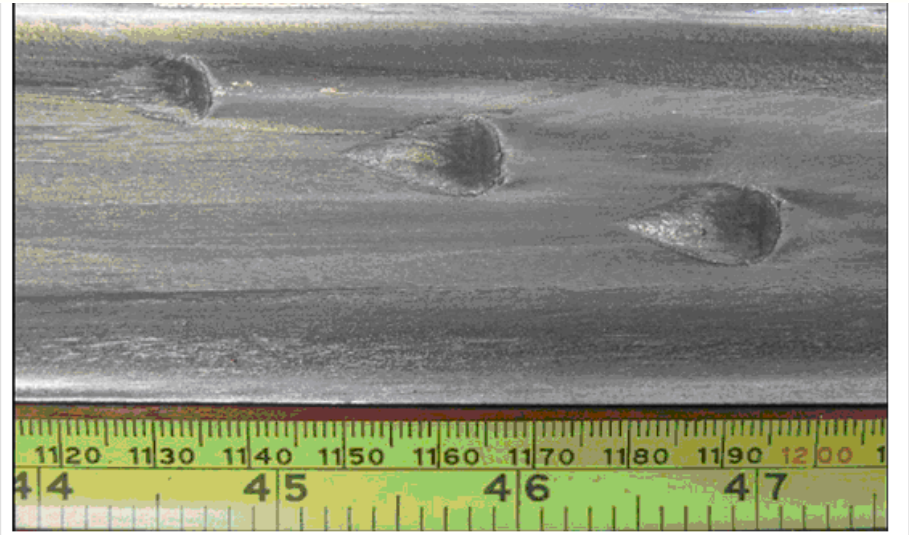
3 Results and Discussions

Gouge crater

Simulation:

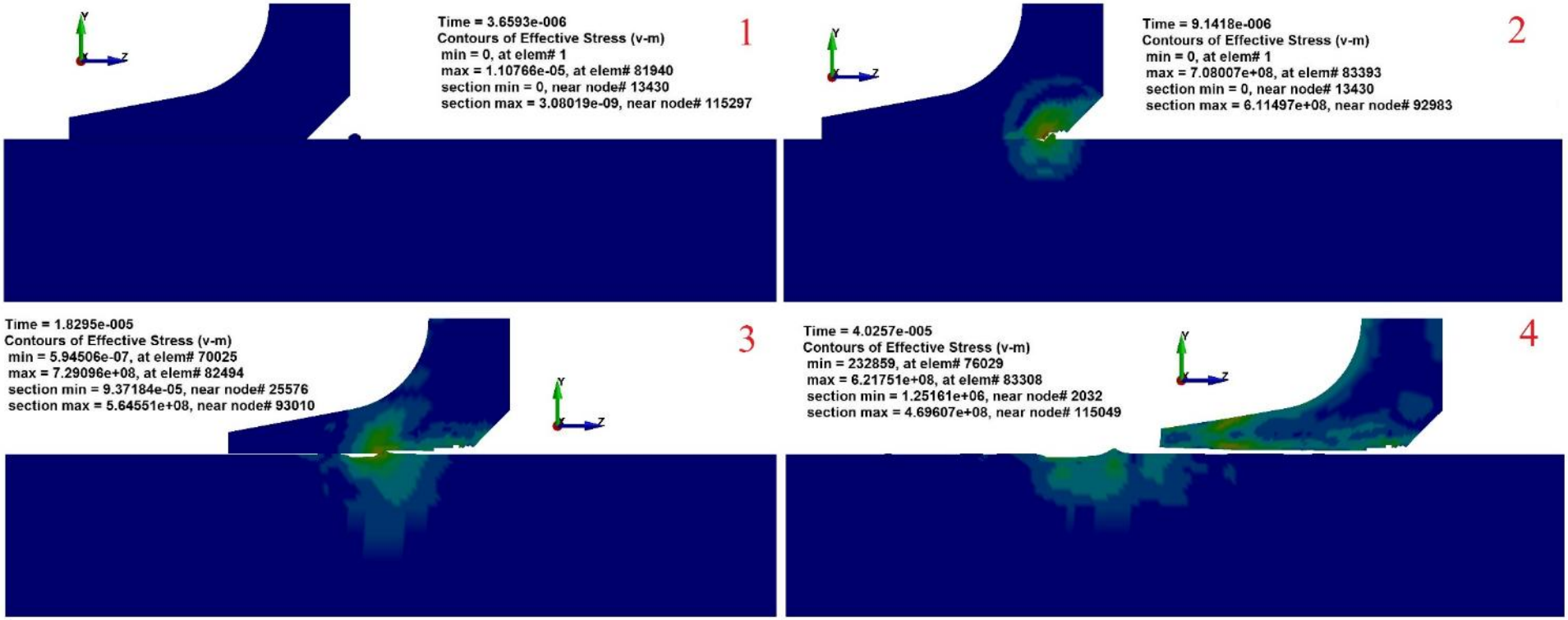


Experiment:



3 Results and Discussions

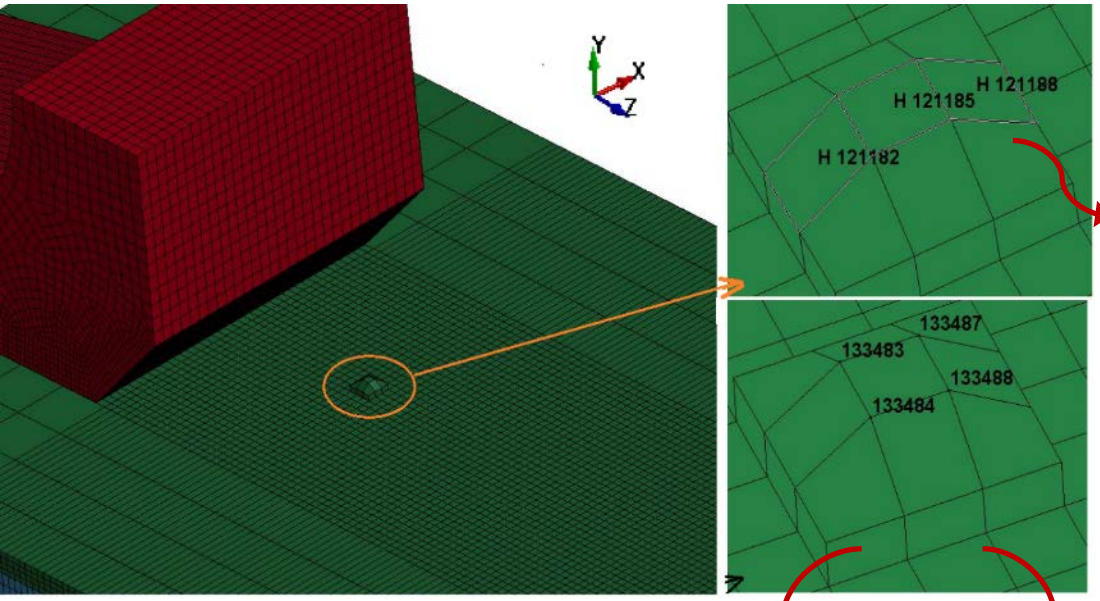
Effective stress on middle section during gouging：

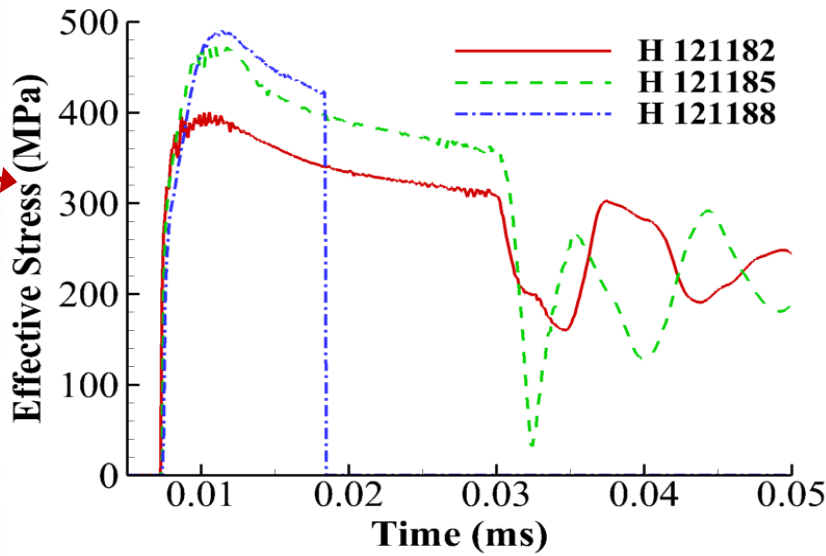


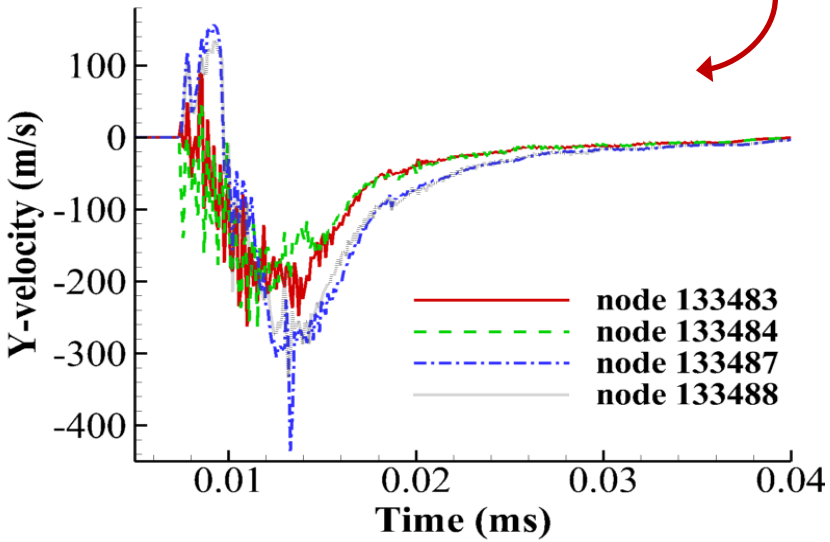
Velocity : 2000 m/s
Rail bulge size : 1 mm
Interaction time : 28 μs

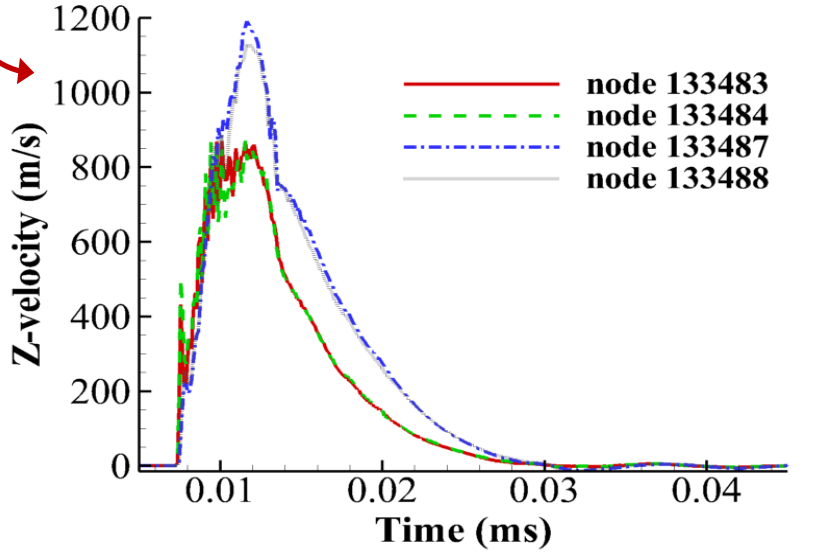
Mises stress: ~ 700 MPa
Pressure: ~ 7 GPa
Temperature rise: ~ 300 °C

3 Results and Discussions









3 Results and Discussions

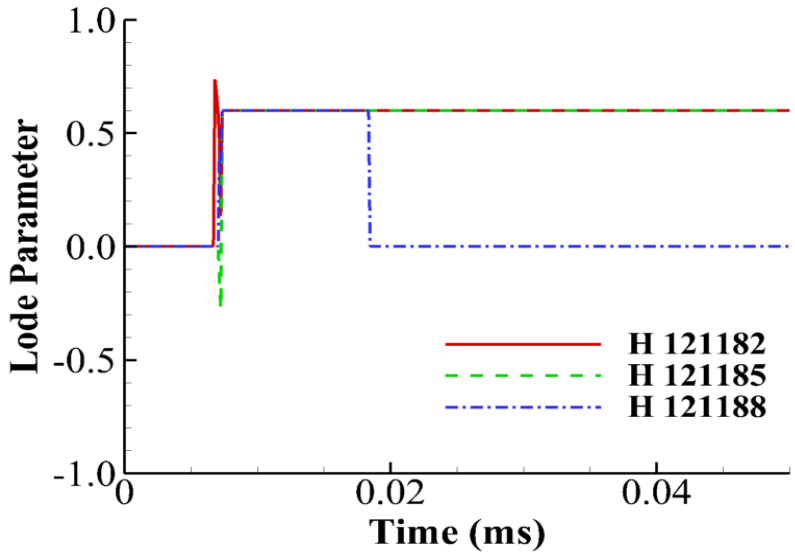
Lode Parameter

$$\mu_\sigma = \frac{2\sigma_2 - (\sigma_1 + \sigma_3)}{\sigma_1 - \sigma_3}$$

Where , σ_1 1st - principal stress

σ_2 2nd - principal stress

σ_3 3rd - principal stress



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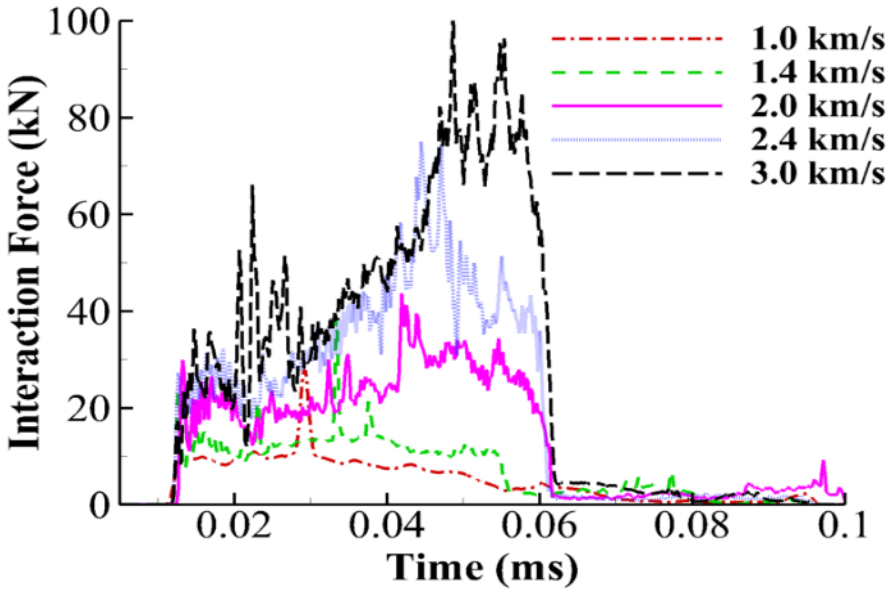
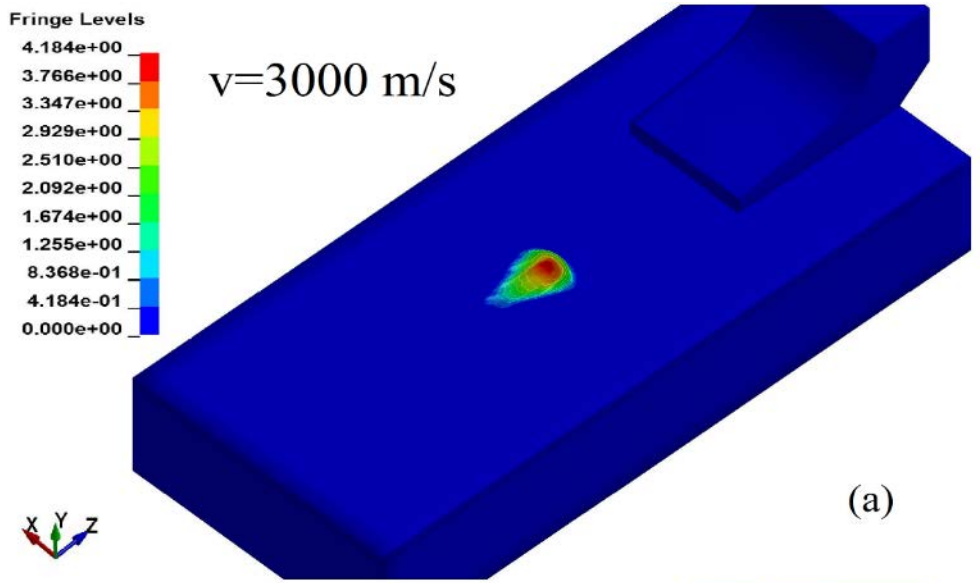
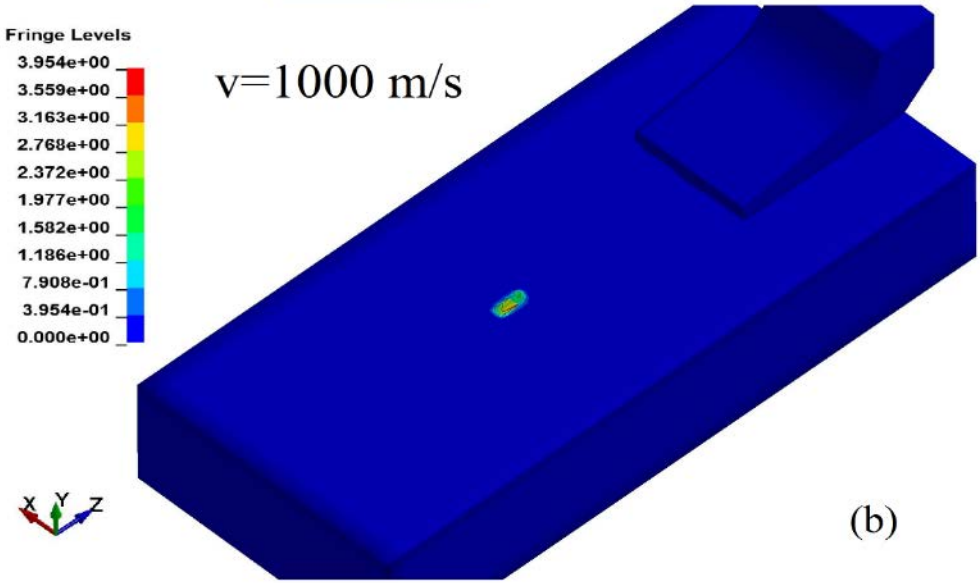
4 Influencing Factors Analysis

velocity



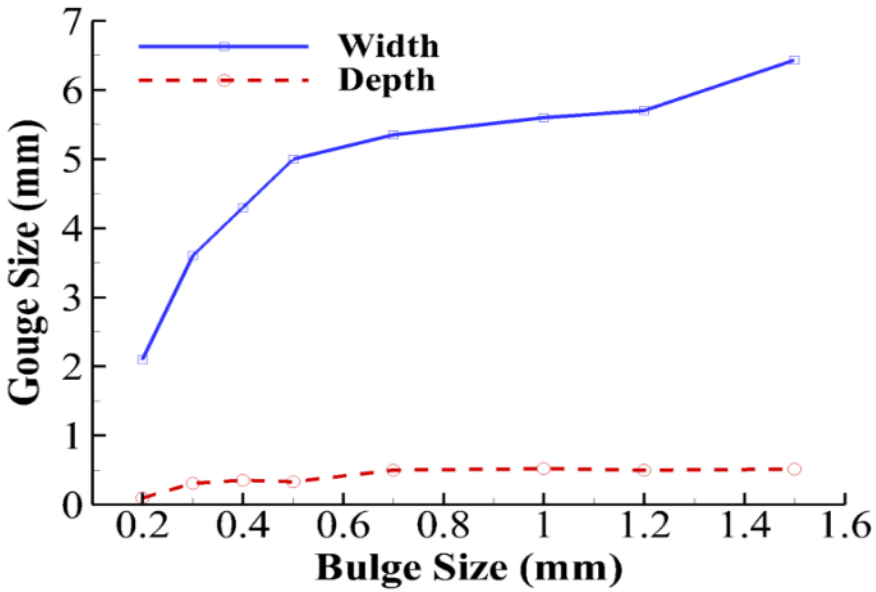


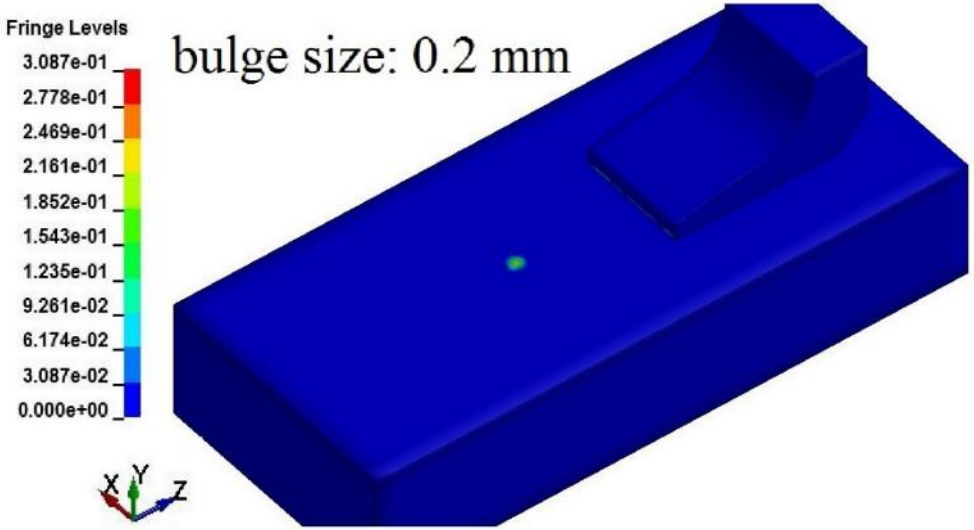


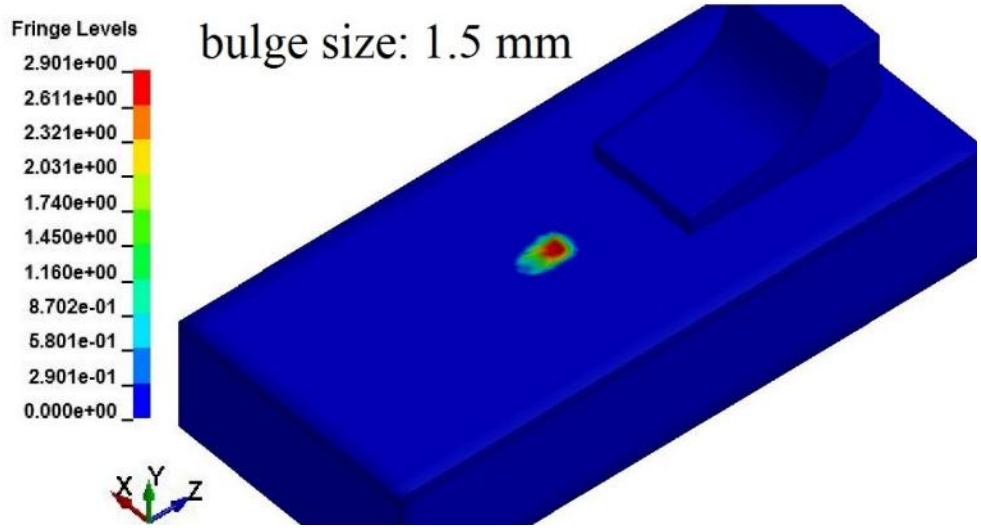
Threshold velocity : ~1400 m/s

4 Influencing Factors Analysis

bulge size





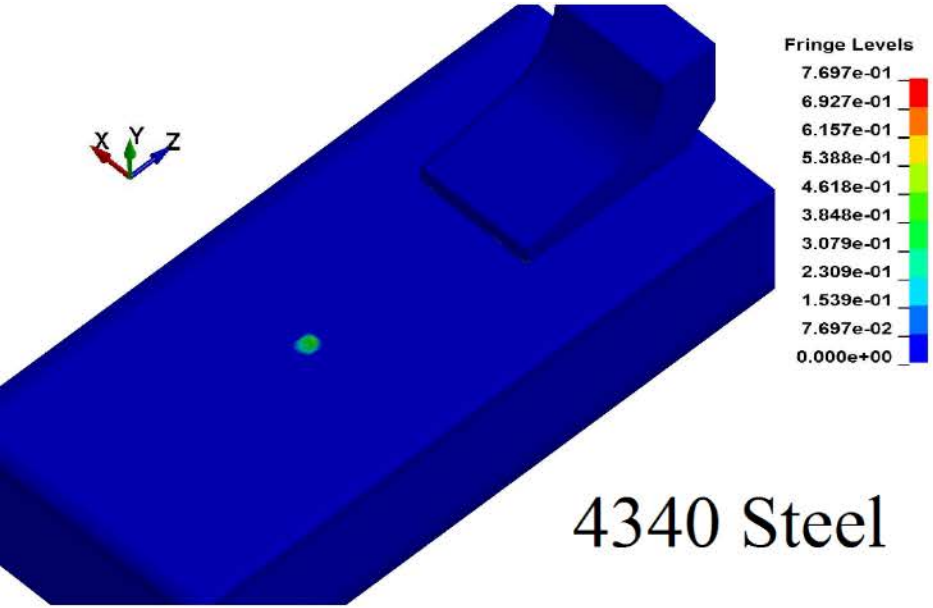


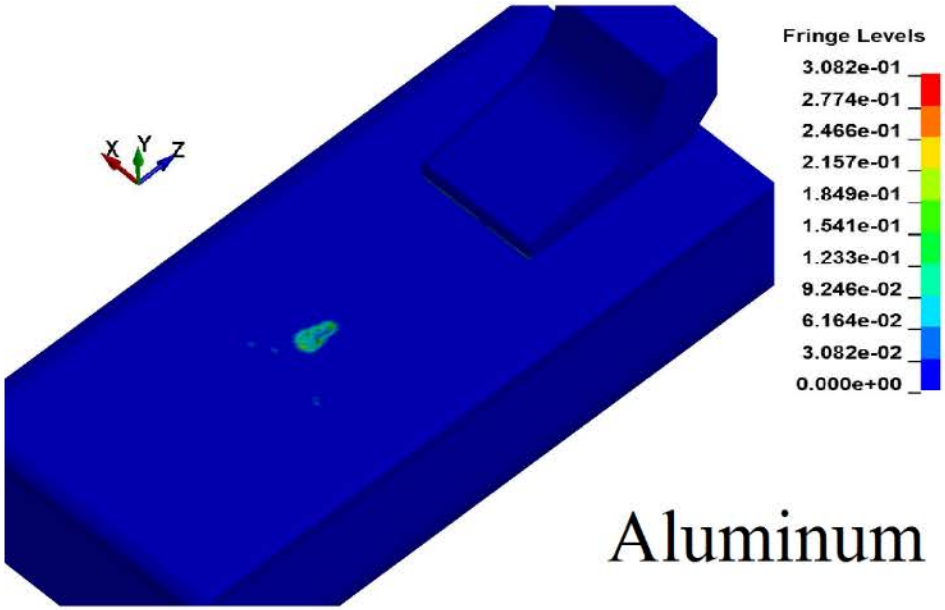
4 Influencing Factors Analysis

materials

Table 2 Three kinds of coating materials

No.	Armature	Rail base	Rail coating
1	7075 Al	OFHC Copper	Cartridge brass
2	7075 Al	OFHC Copper	4340 Steel
3	7075 Al	OFHC Copper	Aluminum





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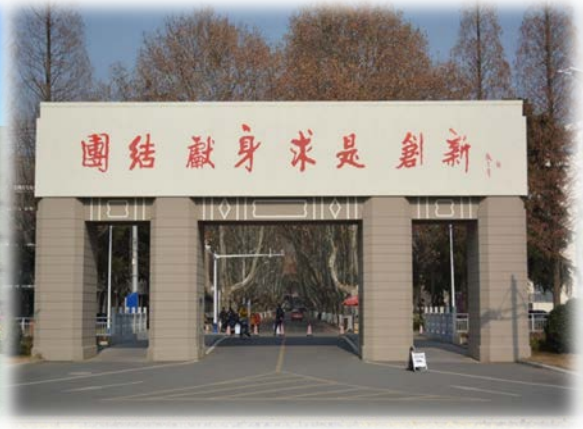
- Micro impacts with mm level on the interface between armature and rail at a high speed are very likely to induce the appear of gouging.
- High density and high pressure material flow generated from impact obliquely extrudes into the rail, illustrates the formation process of gouging.
- For any pair of contact materials , there is a threshold velocity for the formation of gouging. And below the velocity, rail galling is more likely to appear.
- Gouging can be suppressed by controlling the rail bulge size to a certain range and selecting suitable materials for rail surface coating.

Thank You !

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