ЛИТЕЙНОЕ ПРОИЗВОДСТВО

МЕЖДУНАРОДНАЯ НАУЧНО-ТЕХНИЧЕСКАЯ КОНФЕРЕНЦИЯ «ЛИТЕЙНОЕ ПРОИЗВОДСТВО И МЕТАЛЛУРГИЯ 2017. БЕЛАРУСЬ»

Поступила 08.09.2017

DYNAMIC DEFORMATION BEHAVIOR OF 7055/7A52 ALUMINUM CLAD ALLOY UNDER HIGH STRAIN RATES BY USING A SHPB

ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ ДЕФОРМАЦИИ АЛЮМИНИЕВОГО СПЛАВА 7055/7А52 ПРИ ВЫСОКИХ НАГРУЗКАХ С ИСПОЛЬЗОВАНИЕМ РАЗРЕЗНОГО СТЕРЖНЯ ГОПКИНСОНА

ZHENG REN, XIAO ZHANG, XIURONG ZHU, YOUQI WANG, Inner Mongolia Metallic Materials Research Institute. E-mail: renzheng1981@163.com

ЧЖЕН ЖЕНЬ, СЯО ЧЖАН, СЮЖУН ЧЖУ, ЮКИ ВАН, Научно-исследовательский институт металлов Внутренней Монголии. E-mail: renzheng1981@163.com

High strain rate impact tests of 7055/7A52 clad alloy are conducted by using of a SHPB at temperatures ranging from 250 °C to 400 °C and strain rate ranging from 1000 s^{-1} to 3000 s^{-1} to investigate dynamic deformation behavior of 7055/7A52 clad alloy.

The experimental results show that flow stress is influenced by both strain rate and temperatures and more sensitive to the strain rate. Flow stress increases with the strain rate and decreases with the temperatures. Based on the experimental results, a JC model constitute equation is developed to describe the relationship of strain rate ($\dot{\varepsilon}$), deformation temperature (T) and flow stress (σ) and it can predict the flow stress under if the deformation parameters are given.

Динамические испытания скорости относительной деформации алюминиевого сплава 7055/7A52 проводили при использовании SHPB (разрезного стержня Гопкинсона) при температурах от 250 до 400 °С и относительной скорости деформации 1000–3000 $с^{-1}$, чтобы исследовать динамическое поведение сплава 7055/7A52.

Результаты эксперимента показывают, что напряжение текучести происходит под влиянием скорости деформации и температуры, более чувствительной и к скорости деформации. Напряжение пластического течения увеличивается при росте скорости деформации и уменьшается с температурой. На основе результатов эксперимента модели JC составлено уравнение для описания влияния взаимосвязи скорости деформации ($\dot{\varepsilon}$), температуры деформации (T) и напряжения пластического течения (σ), что позволит предсказать напряжение пластического течения, если даны параметры деформации.

Keywords. 7055/7A52, *SHPB, high strain rate.*

Ключевые *слова. 7055/7A52, SHPB – разрезной стержень Гопкинсона, высокая скорость деформации.*

Introduction

Aluminum clad alloy products, which combined the individual advantages of the constituent materials, had lots of advantages compared to the normal single alloy[1–3]. 7055/7A52 aluminum clad alloy compared to traditional metal armors have higher level of protection ability, can enhance the viability of the weapon systems. Therefore, they can be widely used in aircrafts, ground vehicles, ships, individual protections and some other fields. The damage mechanism of clad alloy under impact loads, which is different compare to traditional metal, is a key for armor structure design and ballistic performance evaluation[4].

Split Hopkinson pressure bar (SHPB) is widely used in investigating dynamic behaviors of materials under high strain rate[5–9]. The schematic of a SHPB is shown in Fig. 1. A cylindrical specimen is set between the incident and transmitter bars and a constant amplitude elastic wave is generated by the striker bar. The SHPB can provide a strain rate at the level of 10^4, which can effectively simulate the impact of a bullet.

In this paper dynamic deformation behavior of 7055/7A52 aluminum clad alloy is studied by the use of a SHPB. The influence of strain rate and deformation temperature on the damage mechanism is studied. The results will be very useful to the design of 7055/7A52 aluminum clad alloy.

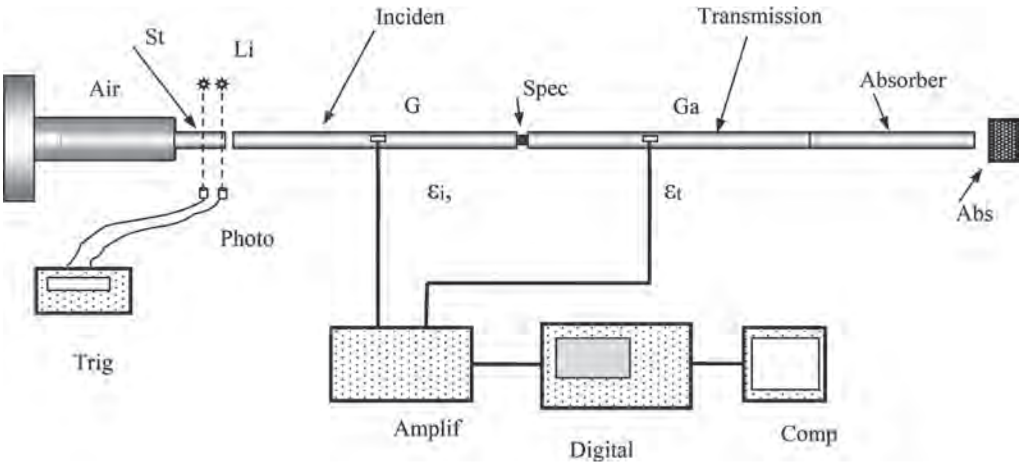


Fig. 1. Schematic of SHPB

Materials and Experimental

The 7055/7A52 aluminum clad alloy was achieved in a former study [10] and chemical composition was shown in Tab.1(mass fraction). After T6 treatment, the 7055/7A52 aluminum clad alloy was cut into column with a shape of 5mm in diameter and 6mm in height (3mm of 7055 and 3mm of 7A52).

The dynamic compression test was conducted by the use of SHPB. The nominal strain rate was selected from 1000s^{-1} to 3000s^{-1}, and the deformation temperature was selected from 250℃ to 400℃. The simples for optical microstropy were polished, and then etched in a solution of 0.5% HF. The microstructures were investigated by optical microscope (ZEISS Imager A2m). The morphology of fracture surface was observed by scanning electron microscope (Quanta 250 FEG).

Results and discussion

Specimens after impact

The specimens after dynamic impact under different temperature and strain rate were shown in Fig. 2. As shown in the picture. When impact at the strain rate of 1000 s^{-1} and 2000 s^{-1}, specimens remains complete in despite of deformation temperature. On the contrary, when impact at the strain rate of 3000 s^{-1}, specimens suffer severe deformation and could not maintain integrity in temperature range from 250 ℃ to 400 ℃. This phenomena suggest that 7055/7A52 clad alloy is more sensitive to strain rate rather than deformation temperature. Also the specimens exhibit asymmetry plastic deformation after impact under the strain rate of 1000 s^{-1} and 2000 s^{-1}. The 7A52 layer suffers more deformation than the 7055 layer. This mainly depends on the mechanical property of each individual layer. The 7055 alloy has a higher yield stress than 7A52 alloy which means the 7A52 layer suffer the deformation before the 7055 layer. So the deformation main concern in the 7A52 layer and exhibit asymmetry plastic deformation.

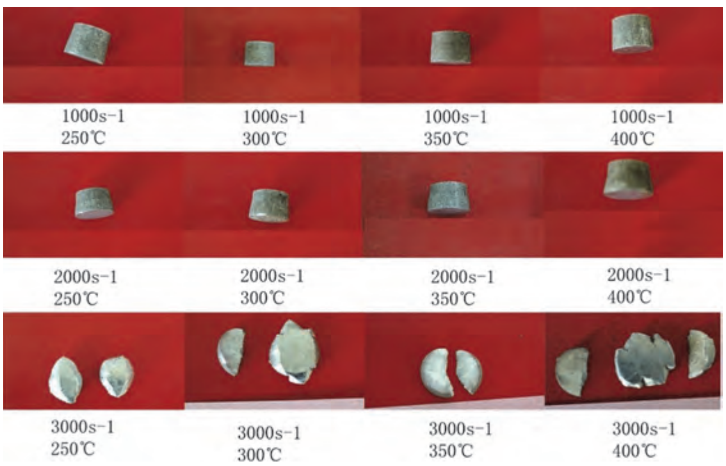


Fig. 2. Specimens after SHPB impact

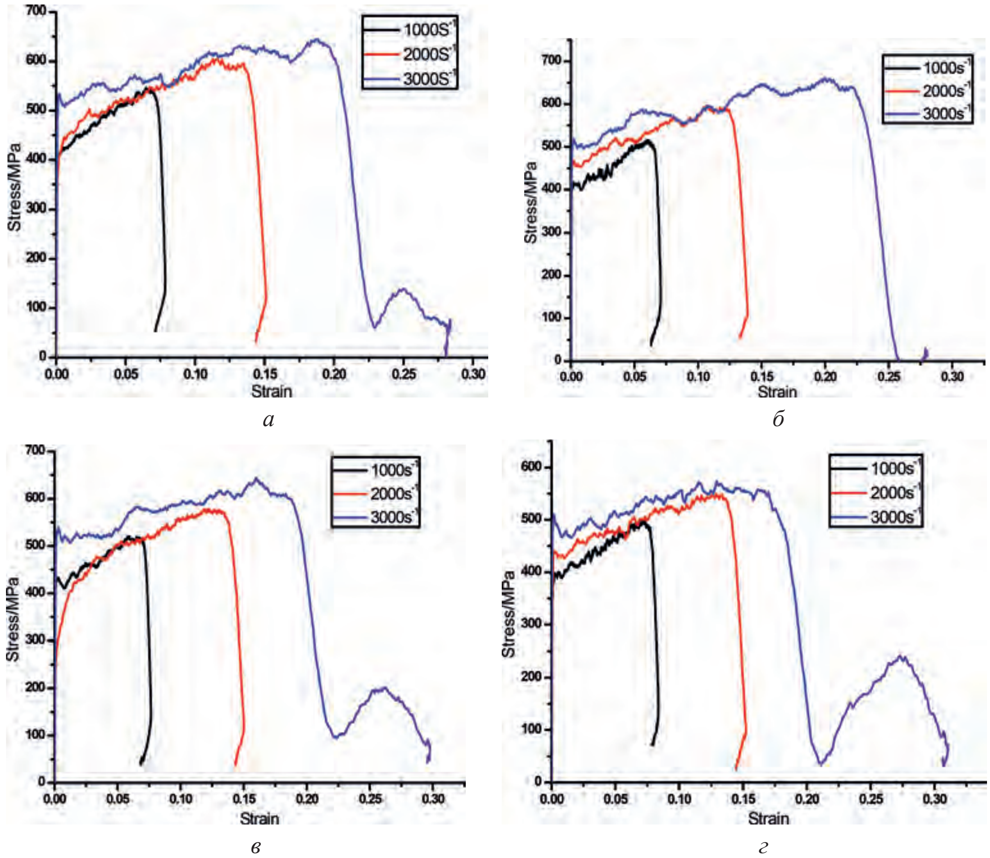


Fig. 3. Flow stresses of 7055/7A52 clad alloy under SHPB impact: *a* – 250 °C; *b* –300 °C *c* – 350°C; *d* – 400 °C

Flow behavior

Fig. 3 showed flow stresses of 7055/7A52 clad alloy under different temperature. The results show that the flow stress increases with the strain rate under a certain deformation temperature. Strain rate influence the flow stress complicated. A higher strain rate means a higher dislocations density and a higher flow stress due to work hardening depends on the dislocations density. On the other hand, a higher strain rate brings more deformation heat and accelerate the dynamic soften behavior which reduce the flow stress. In current study the flow stress of 7055/7A52 clad alloy increase with the strain rate, this indicates that 7055/7A52 clad alloy possess a positive strain rate sensitivity under current deformation condition. When impact at different temperatures under the same strain rate the flow stresses change little. This indicates that 7055/7A52 clad alloy was not sensitive to the deformation temperature.

Microstructure

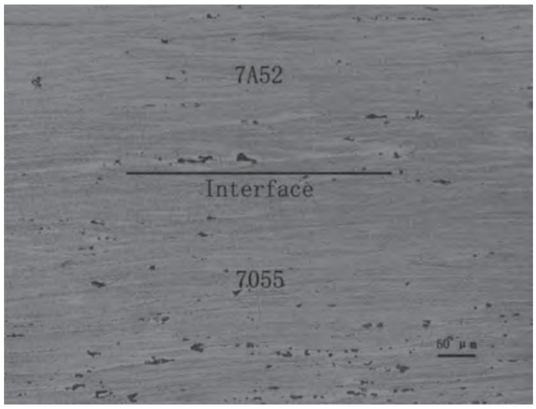
Fig. 4 shows the microstructure of 7055/7A52 clad alloy after impact under different deformation parameter. The mainly difference between 7055 layer and 7A52 layer was the quantities of second phase as seen in Fig. 4. This may be caused by the additional Cu content in 7055 alloy. Comparing Fig. 4, *a*, *b* and *c* it can be conclude that the quantities of second phase increase with the strain rate at the same temperature and decrease with the temperature at the same strain rate. The precipitation of second phase was controlled by the nucleation of the second phase. A higher strain rate brings more defects in the materials such as the vacancies and dislocations. And the defects in materials can promote the nucleation of the second phase. A higher deformation temperature at the same strain rate means a higher solid solubility of alloying elements, so the precipitation of second phase decreases.

Constitute equations

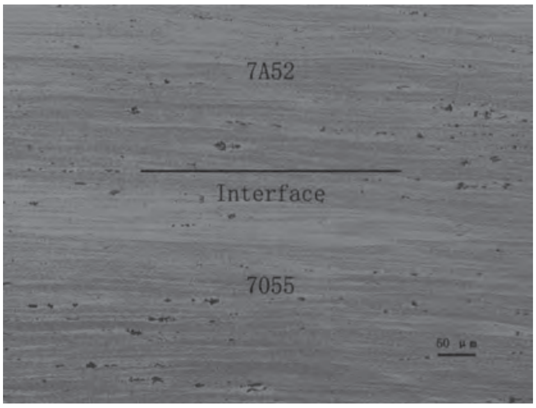
J-C model was an empirical one developed by Johnson and Cook in 1983, which can predict flow stress of metals subjected to large strain, high stain rates and high temperatures. It was expressed as a function of temperature, strain rate and strain as follows [11–14].

$$\sigma = \left(A + B\varepsilon^n\right)\left(1 + C\ln(1 + \dot{\varepsilon}/\dot{\varepsilon}_0\right)\left(1 - \frac{T - T_r}{T_m - T_r}\right)$$

а



б



в

Fig. 4. Microstructure of 7055/7A52 clad alloy: *a* – 1000 s^{-1} 350 °C; *b* – 2000 s^{-1} 350 °C; *c* – 2000 s^{-1} 400 °C

Reference temperature T_r and melting temperature T_m are 250 ℃ and 640 ℃, respectively. The reference strain rate is 1000 s^{-1}. The five parameters, *A, B, C, n* and *m* were calculated from the experimental data and listed in Table 1.

Tab. 1. **The parameters of JC model constitute equation**

Parameters	*A* (MPa)	*B* (MPa)	n	C	m
Value	408	2041.1	0.96776	0.11588	0.18612

Finally, the JC model constitute equation is determined i. e.:

$$\sigma = \left(408 + 2041.1\varepsilon^{0.96776}\right)\left(1 + 0.11588\ln\frac{\dot{\varepsilon}}{1000}\right)\left(1 - \left(\frac{T-523}{390}\right)^{0.70142}\right).$$

Conclusions

In this paper, high speed impact tests of 7055/7A52 clad alloy are conducted using SHPB to investigate dynamic deformation behavior of 7055/7A52 clad alloy. Based on the experimental true stress versus true strain data JC model constitute equation is developed. The main conclusions are as follows:

(1) The flow stress of 7055/7A52 clad alloy under high strain rate increases rapidly to a peak value at initial stage then goes into a steady stage. The flow stress is more sensitive to the strain rate rather than the deformation temperature and exhibit a positive strain rate sensitivity

(2)J-C model constitute equation is developed to predict the flow stress under a certain deformation parameters. The constitute equation can be expressed as:

$$\sigma = \left(408 + 2041.1\varepsilon^{0.96776}\right)\left(1 + 0.11588\ln\frac{\dot{\varepsilon}}{1000}\right)\left(1 - \left(\frac{T-523}{390}\right)^{0.70142}\right).$$

Acknowledgements: The authors would like to gratefully acknowledge the support of Natural Science Foundation of Zhejiang (No. 2016C31030) and Natural Science Foundation of China (No. 51601171).

References

[1] XP Zhang, MJ Tan, TH Yang, et al. Bonding strength of Al/Mg/Al alloy tri-metallic laminates fabricated by hot rolling. Bull. Mater. Sci. 2011; 34: 805–810.

[2] Mojtaba Movahedi, Amir-Hossein Kokabi, Hamid-Reza Madaah-Hosseini, et al. Roll Bonding Behaviour of Al-3003/Al-4043 and Al-3003/Zn Sheets. Met. Mater. Int. 2011; 4: 665–670.

[3] Amir R. Baserinia, Etienne J. F. R. Caron, Mary A. Wells, et al. A Numerical Study of the Direct-Chill Co-Casting of Aluminum Ingots via Fusion^{TM} Technology. Metall Mater Trans B. 2013; 44: 1017–1029.

[4] Zhang Zuoguan, Wang Mingchao, Song Shuncheng. et al. Influence of panel/back thickness on impact damage behavior of alumina/aluminum armors. Journal of the European Ceramic Society. 2010; 30: 875–887.

[5] Xiuli Fu, Xing Ai, Song Zhang. et al. Constitutive Equation for 7050 Aluminum Alloy at High Temperatures. Materials Science Forurn. 2006; 532–533: 125–128.

[6] Chen Guang, Ke Zhihong, Ken Chengzu. et al. Constitutive Modeling for Ti-6A1–4V Alloy Machining Based on the SHPB Tests and Simulation. Chinese Journal Of Mechanical Engineering. 2016; 29: 962–970.

[7] B. Song, W. Chen, B. R. Antoun. et al. Determination of Early Flow Stress for Ductile Specimens at High Strain Rates by Using a SHPB. Experimental Mechanics 2007;47:671–679.

[8] Ouk Sub Lee, Guan Hee Kim, Myun Soo Kim. et al. Dynamic Deformation Behavior of Aluminum Alloys Under High Strain Rate Compressive/Tensile Loading. KSME Iternational Journal, 2003; 17: 787–795.

[9] M. Guden, LW. Hallb. High strain rate deformation behavior of a continuous fiber reinforced aluminum metal matrix composite. Computers and Structures. 2000;76:139–144

[10] Zheng Ren, Xiurong Zhu, et al. Study on direct chill casting of 3003/4004 clad slab. Advanced Materials Research.2012;479:318–321.

[11] Johnson GR, Cook WH. A constitutive model and data for metals subjected to large strains, high strain rates and high temperatures. In: Proceedings of the 7th international symposium on ballistics, Den Haag, The Netherlands; 1983: 541–547.

[12] Johnson GR, Cook WH. Fracture Characteristics Of Three Metals Subjected To Various Strains, Strain Rates, Temperatures and pressures. Eng Fracture Mech. 1985; 21:31–48.

[13] A. Abbasi-Bani, A. Zarei-Hanzaki, M. H. Pishbin, et al. A comparative study on the capability of Johnson–Cook and Arrhenius-type constitutive equations to describe the flow behavior of Mg–6Al–1Zn alloy. Mech Mater. 2014; 71:52–61.

[14] A. S. Milani, W. Dabboussi, J. A. Nemes, et al. An improved multi-objective identification of Johnson–Cook material parameters. Int J Impact Eng. 2009; 36:294–302.