

# Research Status of Ultrasonic Vibration Assisted Plastic Forming Process

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**Abstract:** Ultrasonic vibration assisted plastic forming is a process method for assisting the forming of metal materials by means of ultrasonic vibration devices. It is proved that the ultrasonic vibration could reduce the forming force, improve the friction environment, and enhance the formability of the metal material. However, there are some differences in forming characteristics for different materials under different vibrational plastic forming processes. In this paper, the forming principles, the vibration application modes and the forming characteristics of the ultrasonic vibration assisted the wire drawing, equal channel angular pressing (ECAP), upsetting, drawing of the sheets and hydroforming of the tube are reviewed. It emphasizes on the various processes' improvement of the forming efficiency and the quality of the formed parts under the aid of ultrasonic vibration. Finally, the future development trend of ultrasonic vibration assisted plastic forming was prospected.

## 1. Introduction

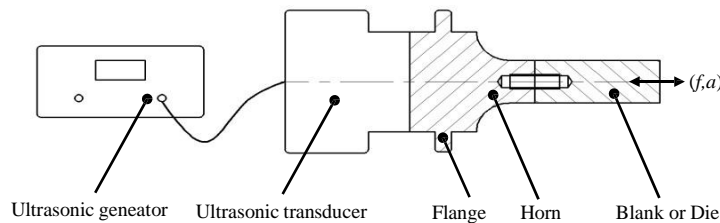
On the basis of the conventional plastic forming, adopting the ultrasonic vibration device to the blank or the tool with an adjustable ultrasonic vibration can obtain a better forming effect. There are two main effects on the mechanism of ultrasonic vibration [1]: one is the volume effect that acts on the inside of the material and affects the flow stress of the material, which mainly explains by the two theories of thermal softening effect and mechanical superposition principle related to crystal dislocation[2]. The other is the surface effect acting on the outside of the material which affects the contact condition between the material and the die, which mainly explains by the reduction of friction and the reversal of the friction vector [3].

The ultrasonic vibration apparatus is mainly composed of an ultrasonic generator, a transducer, a horn and a blank or a die [4, 5], as shown in Fig1. The function of the ultrasonic generator is to convert the alternating current into an electrical oscillating signal. The output power is usually 1~2



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kW, and the vibration frequency is generally 20 kHz. It mainly provides the energy for generating reciprocating vibration. The function of the transducer is to convert the electrical oscillation signal into mechanical vibration, and the amplitude is generally less than 10  $\mu\text{m}$ . The function of the horn is to amplify the amplitude generated by the transducer to suit different working conditions, and the amplitude after amplification is up to 100~150  $\mu\text{m}$ . The blank or die is usually connected to the horn by screws, and the whole apparatus is connected to the device through the flange on the horn to provide high frequency ultrasonic vibration[6].



**Fig 1.** Ultrasonic vibration apparatus

Based on the brief introduction of the ultrasonic vibration apparatus and the mechanism of action above, the following research situation is reviewed from the of ultrasonic vibration's forming principles, the vibration application method and the forming characteristic, such as the assisted drawing, the equal channel angular pressing (ECAP), the upsetting, the drawing of the sheet and the hydroforming of the tube and so on, which provides a new reference method and ideas for the application and promotion of ultrasonic vibration in the field of plastic forming.

## 2. Ultrasonic vibration assisted wire drawing

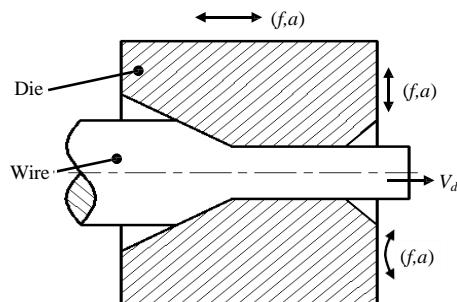
Ultrasonic vibration wire drawing is based on the traditional drawing, applying vibration to the wire drawing die for vibration drawing, as show in Fig 2. For easy-to-machine materials such as pure aluminum and stainless steel, radial vibration is superior to axial vibration in improving tensile speed and improving surface forming quality [7], but radial vibration is not as good as axial vibration in reducing drawing force [8]. And the critical speed at break is 14.9% higher than that of conventional wire drawing [9]. For the difficult-to-machine material of titanium, Yang et al.[10] found in the drawing test in 2016 that the longitudinal-torsional composite vibration drawing force was reduced by 15.6% compared with the longitudinal vibration, but the friction was slightly increased and the surface quality was poor. In 2017 and 2018, Liu et al.[11,12] found that compared with conventional drawing, large amplitude longitudinal vibration and longitudinal-torsion composite vibration could improve the surface quality, and large amplitude longitudinal vibration was more effective in reducing the drawing force. In addition, in the wire drawing test of the longitudinal vibration of two passes, the drawing force was reduced by 50%, and the effect of increasing the wire speed and improving the surface quality was better than increasing the amplitude.

It can be seen that ultrasonic vibration exhibits good characteristics for easy-to-machine materials and difficult-to-machine materials in wire drawing. Moreover, in the vibration state, the drawing pass of the blank can be reduced, and multiple passes can be performed, which significantly improves the processing efficiency and forming performance of the material.

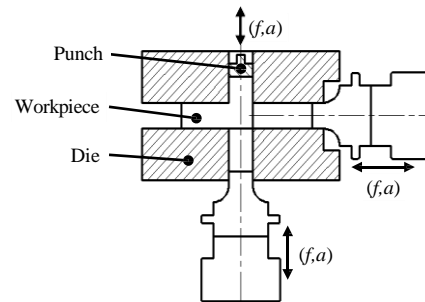
## 3. Ultrasonic vibration assisted ECAP

ECAP is an important technical for achieving ultra-fine grain structure, and the vibration application way is shown in Fig 3. In 2014, Ahmadi et al. [13] constructed a simulation model of rigid and plastic pressing punch, and found that the simulation error of the plastic pressing punch was only 0.6% while

the simulation error of the rigid body pressing punch was 7.3%. The plastic model was closer to the actual machining environment. In 2015, Ahmadi et al. [14] found that the grain refining efficiency increased by 25.8% after the vibration pressing of pure aluminum, and microstructure were more uniform by increasing the amplitude. In 2016, Bagherzadeh et al. [15] applied longitudinal or transverse ultrasonic vibration directly to the deformation zone in the vibrational equal channel angular pressing of pure aluminum. The pressing force was reduced by about 30%, the hardness was increased by 50% to 52.9%. Moreover, the effect in refining the grains, reducing the pressing force, strengthening the hardness, and the longitudinal vibration is better.



**Fig 2.** Ultrasonic vibration wire drawing process

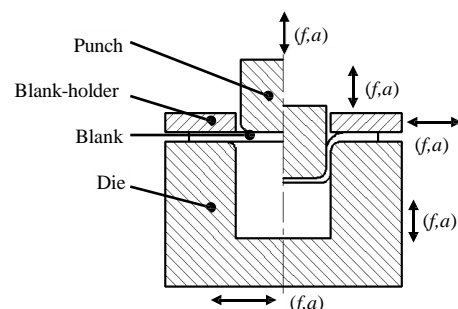


**Fig 3.** Ultrasonic vibration ECPA

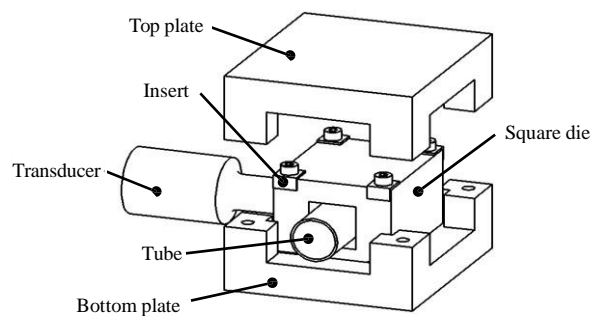
It can be seen that in the extrusion forming, the ultrasonic vibration can reduce the extrusion force, and have higher grain refining efficiency and better hardness strengthening effect. At the same time it make the microstructure of the forming component more uniform. Moreover, in the simulation study, it is very important to construct a reasonable simulation model to improve the accuracy of the simulation study.

#### 4. Ultrasonic vibration assisted deep drawing

Nowadays, ultrasonic vibration deep drawing is mainly used for drawing the thin sheet barrel, and the vibration is applied as shown in Fig 4, and the thick-direction vibration of the blank holder or the die was more obvious for the increase of the limiting drawing ratio[16]. In 2014, Huang et al. [17] found that LDR increased by 8.5%~8.9% and the punching force decreased by 24%~38% in the vibration micro-draw test of stainless steel sheet, effectively overcoming the problem of work hardening. During 2016-2018, CAO et al. [18-20] performed a soft punching of the AZ31B magnesium alloy sheet at a high temperature by longitudinal vibration of the die, and found that the vibration reduced the optimum forming temperature by 10.3%~17.2%. Moreover, the punching force was lowered by about 55.2% at 260°C, the LDR was increased by 22.1%. In addition, in the experimental study on the friction characteristics of the sheet under ultrasonic vibration, it was found that the friction coefficient was reduced by about 40%.



**Fig 4.** Ultrasonic vibration deep drawing process



**Fig 5.** The apparatus of ultrasonic vibration hydroforming of the tube

It can be seen that in the deep drawing, the ultrasonic vibration reduces the punching force, improves the forming limit of the sheet, significantly reduces the friction coefficient during the processing, and overcome the problem of the work hardening of the smaller parts. In addition, for the magnesium alloy sheet which is not easily formed at normal temperature, the optimum forming temperature is effectively lowered, and the processing process is improved.

### **5. Ultrasonic vibration assisted hydroforming of the tube**

At present, the application of ultrasonic vibration in the hydroforming process of tube has gradually gained attention and achieved some results. In 2008, Bauget et al. [21] developed a set of ultrasonic vibration hydroforming apparatus, as shown in Figure 5. In the experimental study of the annealed copper alloy tube, ultrasonic vibration was found to reduce the angular radius of the formed section by 7.7%. In 2015, Shahri [22] changed the position of the gasket on the die based on Bauget, and constructed a two-dimensional rigid square die model. The results showed that the thickness distribution of the formed section was more uniform after applying ultrasonic vibration. The angular filling rate was increased from 55.8% to 92.93%. In 2017, Zarei et al. [23] also used the Bauget's method to fix the die directly without using a gasket. The two-dimensional deformed square die model was used for simulation analysis. It was found that there was a high frequency contact-separation state between the inner surface of the die and the tube. This state improved the friction between the tube and the inner surface of the die, so that the angular radius of the formed component was reduced, the thickness distribution was uniform, and no extreme thinning occurred at the straight side and the rounded corner. In the same year, the team [24] applied ultrasonic vibration along the axial direction in the simulation study of tube hydro forming with axial feeding, and found that increasing the vibration frequency or vibration amplitude can reduce the axial compression load and increase the bulging height.

It can be seen that the ultrasonic vibration in the hydroforming of the tube improves the filling property of the pipe, the moldability and the uniformity of the wall thickness, improves the forming limit of the pipe. But at present, it is basically in the stage of simulation research. Although some scholars have carried out experimental research on the forming properties, when using the forming device developed by the researcher, the volumetric effect of the ultrasonic vibration on the tube was negligible, and it is more suitable for the related research of the surface effect.

### **6. Summary and forecast**

In summary, in the plastic forming process, Ultrasonic vibration plays a very good role in the formation of easy-to-machine materials such as copper, aluminum, stainless steel, and difficult-to-machine materials such as titanium and titanium alloys. It also effectively overcomes the work hardening problem caused by the small size of the small piece. Nevertheless, due to the further research and verification of the mechanism of ultrasonic vibration plastic forming, there is still much work to be done in the future. For example, The different characteristics of friction in different processes and different temperatures, and the depth mechanism need further study. In the simulation study of ultrasonic vibration plastic forming, the establishment of more accurate theoretical models, material models and friction models can significantly improve the accuracy of research. Moreover, the research and development of high-power ultrasonic vibration devices and forming equipment is crucial for the application and promotion of ultrasonic vibration in the field of plastic forming.

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## References

- [1] Dnwsom G R, WinspeT C E, Sansome D H 1996 *J.Metal Forming*,**231**,234-238.
- [2] Wen T, Li W,Xia C and Chunlei P 2011 *J.International Journal of Minerals, Metallurgy and Materials*,**18**,70-76.
- [3] Storck H, Littmann W, Wallaschek J and Mracek M 2002 *J.Ultrasonics*, **40**,379-383.
- [4] Junwen Z,Shusen W,Youwu M and An P 2008 *J. Materials Review*,**S1**,189-193.
- [5] Yanxiong L and Lin H 2015 *J.Journal of Plasticity Engineering*,**22**,8-14.
- [6] Shendun Z,Yonfeng L and Shuqin F 2013 *J. China Mechanical Emgineering*,2013,24,835-840.
- [7] Murakawa M and Jin M 2001 *J.Journal of Materials and Processing Tcchnology*,113,81-86.
- [8] Hayashi M, Jin M, Thipprakmas S, Murakawa M, Hung J C,Tsai Y C, Hung C H 2003 *J.Journal of Materials Processing Technology*,140,30-35.
- [9] Haiqun Q, Xiaobiao S and Tao X 2009 *J. Chinese Journal of Mechanical Engineering*, 22,580-586.
- [10] Yang C Q,Shen X B and Xie T 2016 *J.The International Journal of Advanced Manufacturing Technology*,2016(1/4):645-655.
- [11] Liu S,Shen X B,Guo K, Yang Y Cand Xie T 2017 *J. Ultrasonics*,**83**,60-67.
- [12] Liu S,Yang Y C,Xie T and Shen X B 2018 Experimental Study on Fine Titanium Wire Drawing with Two Ultrasonically Oscillating Dies *J. IEEEAccess*.
- [13] Ahmadi F,Farzin M 2014 *J.Journal of Mechanical Engineering Science*, **228**,1859-1868.
- [14] Ahmadi F,Farzin M,Meratian M,Loeian S M and Forouzan M R 2015 *J.The International Journal of Advanced Manufacturing Technology*, **79**,503-512.
- [15] Bagherzadeh S,Abrinia K and Han Q Y 2016 *J.Materials Letters*,**169**,90-94.
- [16] Jimma T,Kasuga Y,Iwaki N, Miyazawa O, Mori E,Ito K and Hatano H 1998 *J.Journal of Materials ProcessingTechnology*,406-412.
- [17] Huang Y M,Wu Y S and Huang J Y 2014 *J.The International Journal of Advanced Manufacturing Technology*, **71**,1455-1461.
- [18] Cao Miayan,Li Jianchao,Yang Zhuoyun,Zhao Changcai and BI Jiang 2016 *J.Transactions of Nonferrous Metals Society of China*, **26**,2118-2127.(In Chinese)
- [19] Cao M Y,Li J C,Yuan Y N and Zhao C C 2017 *J.Trasaction of Nonferrous Metals Society of china*, **27**,163-171.
- [20] Miaoyan C,Jianchao L,Yanyang L,Yaning Y, Changcai Z and Guo-jiang D *J.Journal of Central South University*, **25**,1879-1887.
- [21] Bunget C 2008 Mechanics of Ultrasonic Tube Hydroforming *D.North Carolina State University*.
- [22] Shahria S E E, Boroughanib S Y A, Khalilib K and Kang B S 2015 *J. Procedia Technology*,90-97.
- [23] Zarei M, Faghani G R,Farzin M and Mashayekhi M 2017 *J.Journal of Applied and Computational Mechanics*, **3**,178-184.
- [24] Zarei M,Faghani G R, Farzin M and Mashayekhi M 2017 *J.Journal of Applied and Computational Mechanics*,**3**,251-257.