Low-Carbon Manufacturing of Metal Forming Machine

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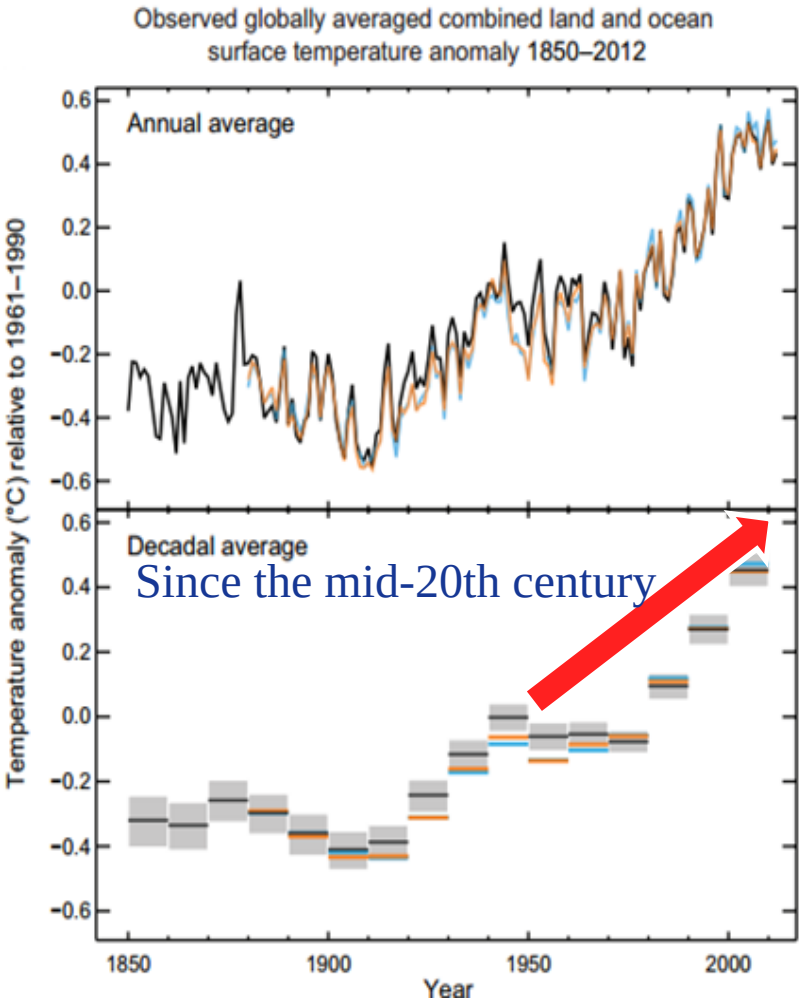
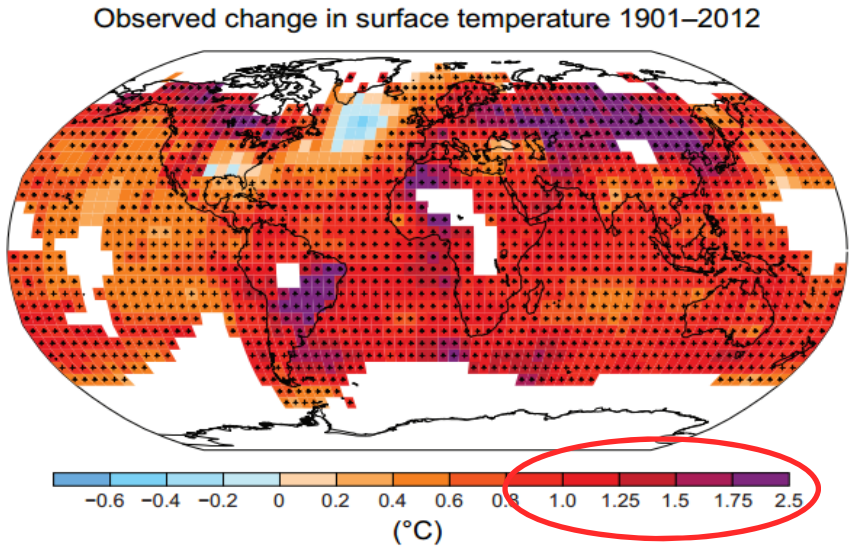
Contents

Why Low-Carbon Manufacturing?



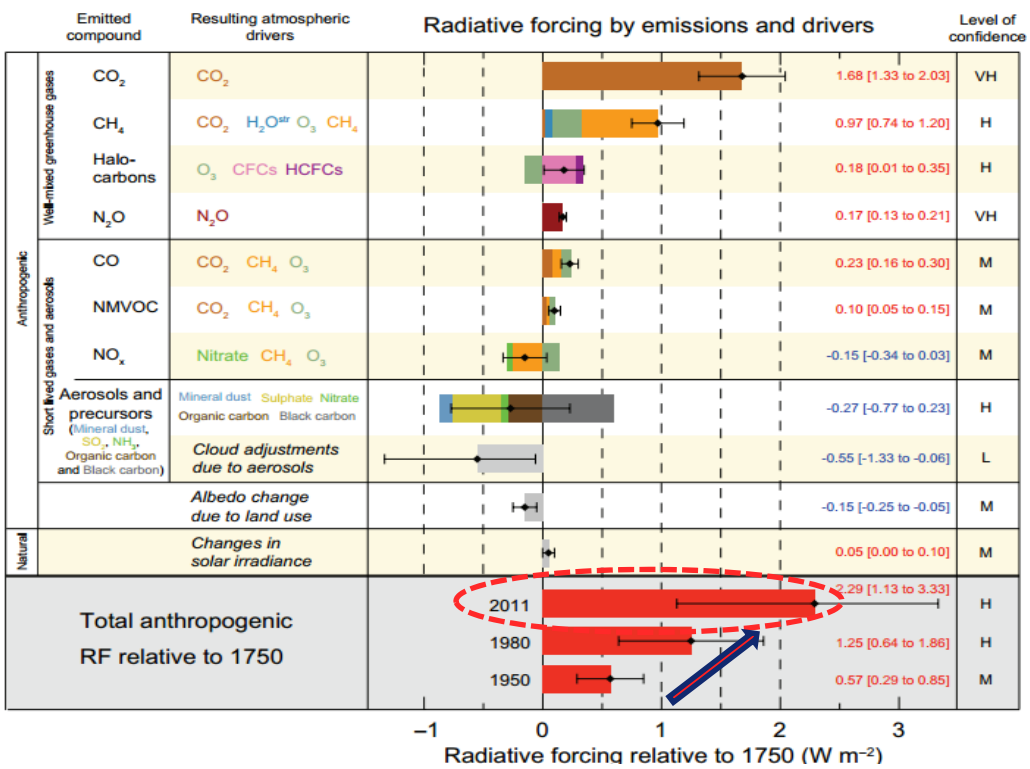


Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

“Natural and anthropogenic substances and processes that alter the earth’s energy budget are drivers of climate change”

Source : Climate Change 2013: The Physical Science Basis

Why Low-Carbon Manufacturing?



Source : Climate Change 2013: The Physical Science Basis

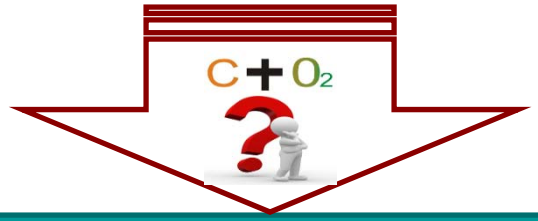
The main human activity that emits CO2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, although certain industrial processes and land-use changes also emit CO2.

List of countries by 2012 emissions estimates

Country	CO_2 emissions[9]	Emission per capita[9]
World	34,500,000	4.9
China	9,860,000	7.1
United States	5,190,000	16.4
India	1,970,000	1.6
Russia	1,770,000	12.4
Japan	1,320,000	10.4
International transport	1,060,000	-
Germany	810,000	9.7
South Korea	640,000	13.0
Canada	560,000	16.0
United Kingdom	490,000	7.7
Mexico	490,000	4.0
Indonesia	490,000	2.0
Saudi Arabia	460,000	16.2
Brazil	460,000	2.3
Australia	430,000	18.8
Iran	410,000	5.3
Italy	390,000	6.3
France	370,000	5.8
South Africa	330,000	6.3
Poland	320,000	8.4

Database created by European Commission and Netherlands Environmental Assessment Agency

Why Low-Carbon Manufacturing?



How to realize low carbon development ?How to achieve reduction targets ?

Emissions pledges

All are for the year 2020

Compared to 1990:
EU: 20% - 30%
Japan: 25%
Russia: 15% - 25%
Ukraine: 20%

Compared to business as usual:
Brazil: 36.1% - 38.9%
Indonesia: 26%
Mexico: 30%
South Africa: 34%
South Korea: 30%

Compared to 2000:
Australia: 5% - 25%

Compared to 2005:
Canada: 17%
US: 17%

Carbon intensity compared to 2005:
China: 40% - 45%
India: 20% - 25%

Source: Who's On Board With The Copenhagen Accord?
http://www.usclimatenetwork.org/policy/copenhagen-accord-commitments

A third of the world's energy consumption and 36% of carbon dioxide (CO2) emissions are attributable to manufacturing.

Manufacturing is an important pillar industry in national economy.

LOW CARBON MANUFACTRURING !

Definitions

◆ Low-carbon Manufacturing

- It is a modern production mode, under the premise of ensuring product's function and quality and considering environmental impact and resource consumption, which uses **carbon dioxide equivalent** as measuring unit and makes product's total carbon emissions minimized and the economic benefits maximized in the entire life cycle from design, manufacturing, transport, use, and to disposal by coordinating optimization within the system boundaries.

Direct

Indirect

Energy consumption

Material consumption

Global Warming Potentials for Common Greenhouse Gases

Gas	GWP (T = 100 years)
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
CFC-11 (CCl_3F)	4,750
Sulfur Hexafluoride (SF_6)	22,800

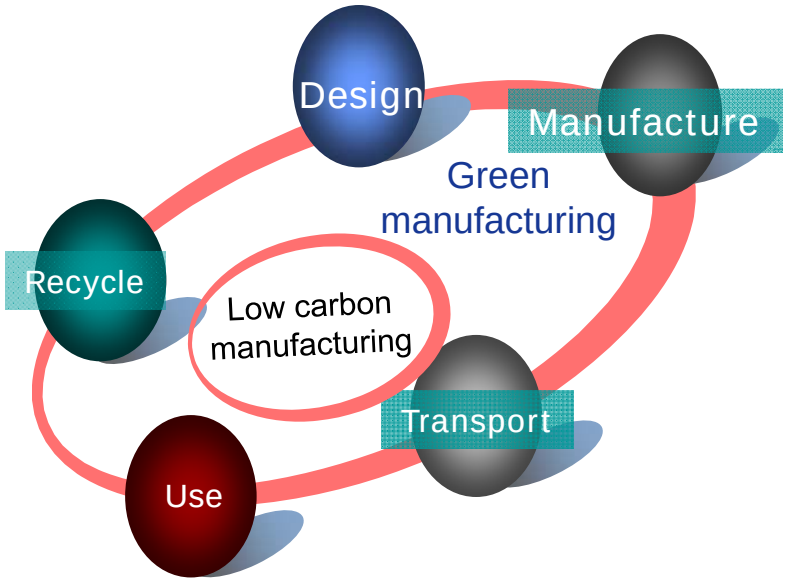
Definitions

- **Low-carbon manufacturing & energy saving, material saving, emissions reducing**

  Low-carbon manufacturing is the integrative optimization of resources, energy, and carbon emissions in the entire product life cycle, based on the life-cycle carbon footprint.

- **Low-carbon manufacturing & green manufacturing**

  Low-carbon manufacturing is derived from the green manufacturing under the background of low-carbon economy to wrestle with the challenges of "energy crisis" and "greenhouse effect."



Related NSFC Research Projects

Some low carbon research projects supported by the NSFC.

No.	Projects	institutions
1	The optimization theories and key technologies of discrete workshop manufacturing system‘s low carbon and efficient operation	Huazhong University of Science and Technology
2	The low-carbon optimization design theory and method of manufacture machine containing unascertained information	Dalian University of Technology
3	Evolutionary methods of extension knowledge orient to low carbon product design‘s conflict coordination	Zhejiang University of Technology
4	Evolutionary design method to integrate low carbon and structure variation	Zhejiang University
5	Low carbon manufacturing oriented model and intelligent analysis method of machining process‘ energy consumption	Zhejiang University
6	Design methods and tools of product’s low carbon innovation	Sichuan University
7	The wisdom technology and system to integrate low carbon design and manufacturing	Zhejiang University
8	**The basic theory and key technology of low carbon manufacturing for High-end metal forming machines**	**Hefei University of Technology**

Summary

(1) Extensive researches on carbon footprint and carbon emissions are performed for the chemical industry, transportation and agriculture. We should also focus on the mechanical manufacturing!

(2) Energy efficiency assessment in manufacturing is one of the hot topics, especially for the CNC machine tools at the machine level and systematic optimization at the workshop level.

Our Target: Metal Forming Machine

Advanced Metal Forming machine

Characteristics: High nominal pressure, high forming precision, high degree of automation.
Typical : large hydraulic press, servo press and mechanical press.

Applications Automobiles, ships, aircrafts, heavy machine tools and other advanced machine manufacturing

Features

- **Huge single weight**
- **Singleton or small quantities**
- **Large installed power**
- **Short effective working time**

About 70% of the metals are made into products by forming. In 2008, steel production in china was 585 million tons with about 840,000 metal forming machines, and the annual processing capacity has approached to 390 million tons.

Annual Power consumption
24 billion KW/h
≈

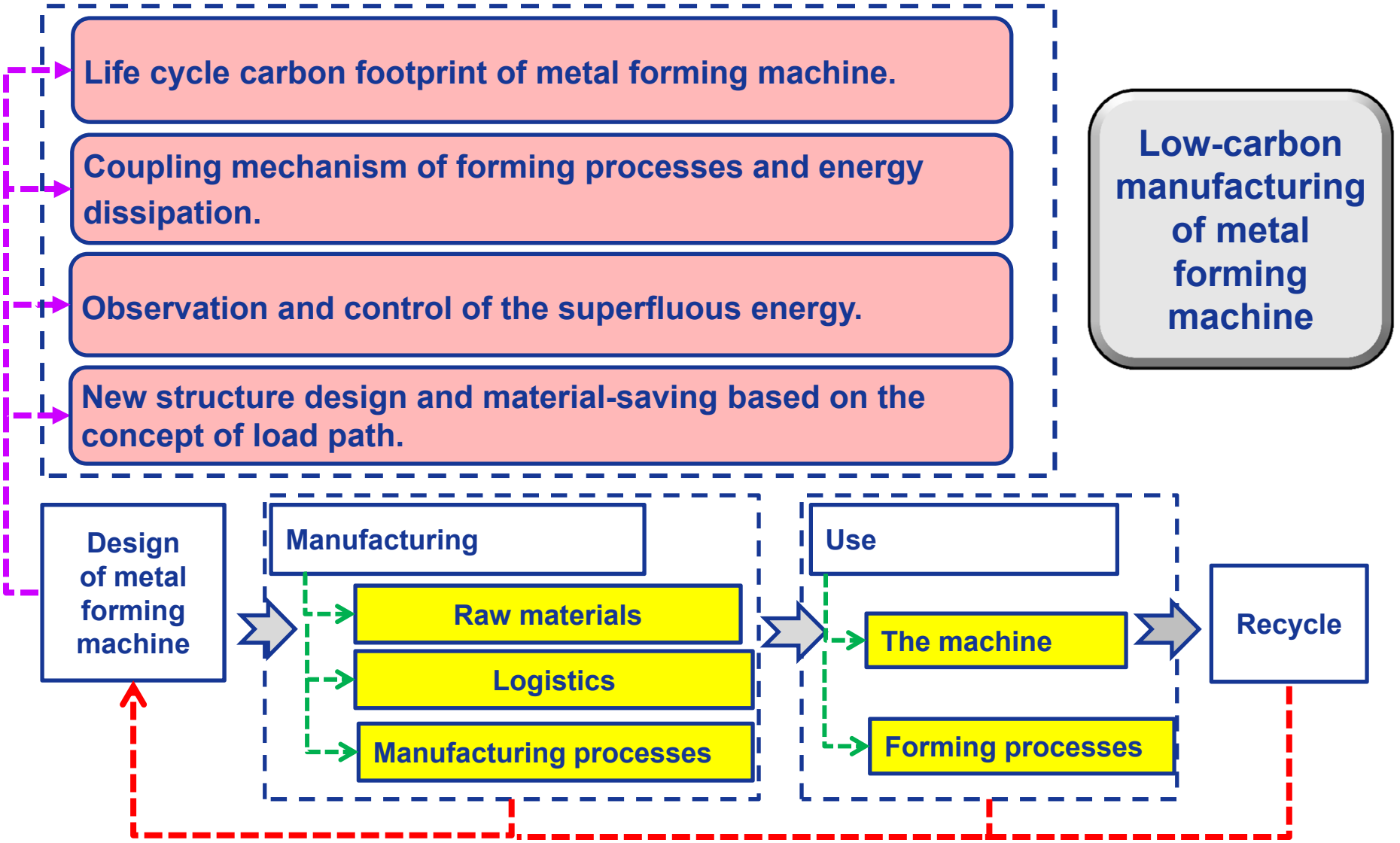
20% power saving
= 20 million tons of carbon emissions

2.45 million hectares of forest

Xiao Hinggan Mountains

The research on the low-carbon manufacturing of advanced metal forming machine is critical and typical!

Concept


Life cycle carbon footprint of metal forming machine.
Coupling mechanism of forming processes and energy dissipation.
Observation and control of the superfluous energy.
New structure design and material-saving based on the concept of load path.
Low-carbon manufacturing of metal forming machine
Design of metal forming machine
Manufacturing
Raw materials
Logistics
Manufacturing processes
Use
The machine
Forming processes
Recycle

Our works

➢ Carbon emissions in manufacturing of the forming machine

$$G_{cut} = M_{steel} \times k_{steel} + M_C \times k_C + M_{O2} \times k_{O2} + M_{CO2} + E_{cut} \times k_{power}$$

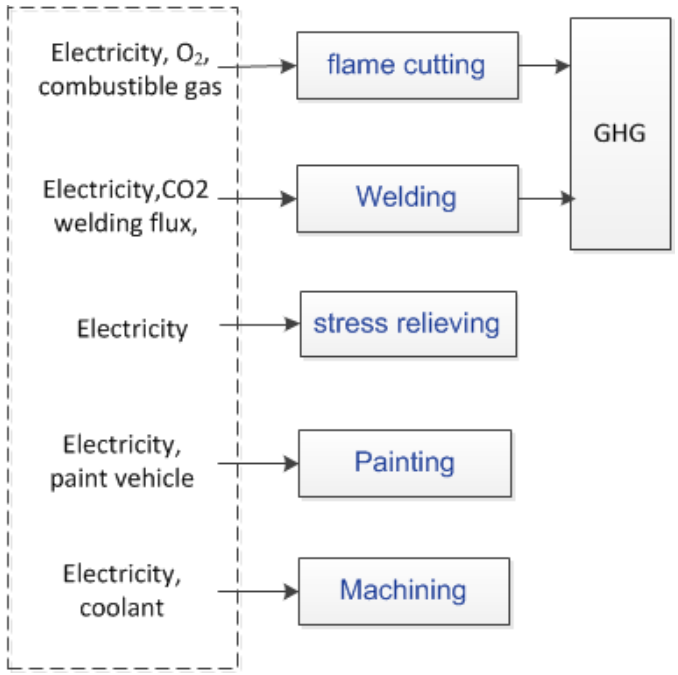
$$G_{wel} = M_{welding} \times k_{welding} + M'_{CO2} \times k_{CO2} + M'_{CO2} + E_{welding} \times k_{power}$$

$$G_{vib} = E_{vib} \times k_{power}$$

$$G_{paint} = S \times k_{s-pri} \times k_{pri} + S \times k_{s-tc} \times k_{tc} + E_{paint} \times k_{power}$$

$$G_{mac} = E_{machining} \times k_{power} + m_{flu} \times k_{flu}$$

Carbon emissions calculation

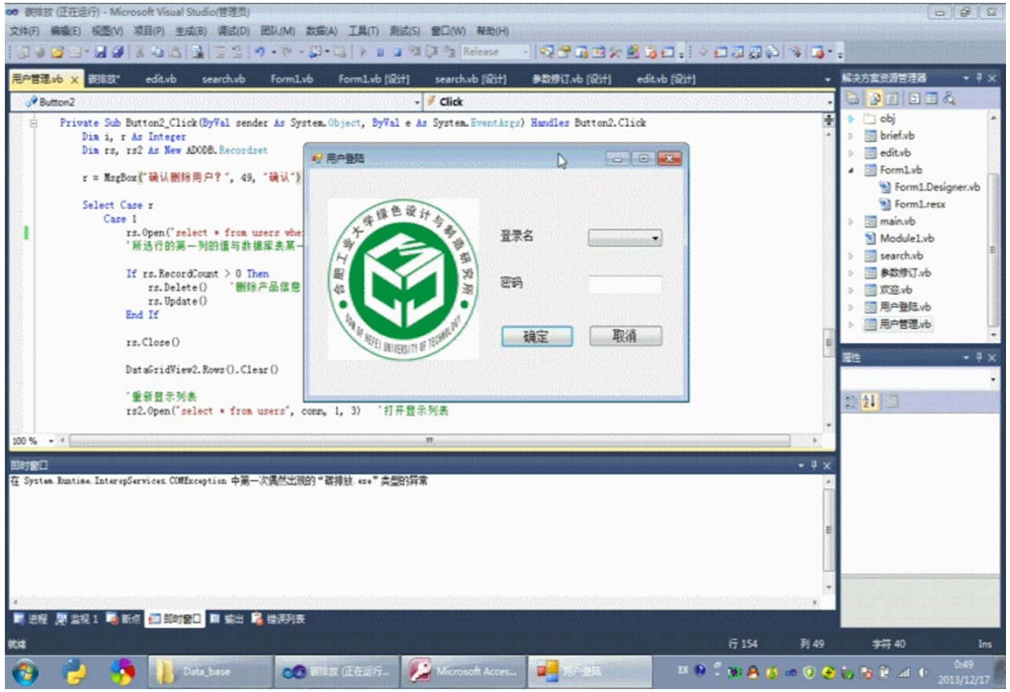


Carbon emissions assessment boundaries

Based on the manufacturing process of metal forming machine, the carbon emissions analysis boundary was determined and major processes are included: flame cutting, welding, stress relieving, painting and machining.

Our works

A life cycle carbon emission calculation and data management system of high-end metal forming machine have been developed – it can identify the key factors contributing to the carbon emissions of a metal forming machine.



Life-cycle carbon emissions calculation and data management system

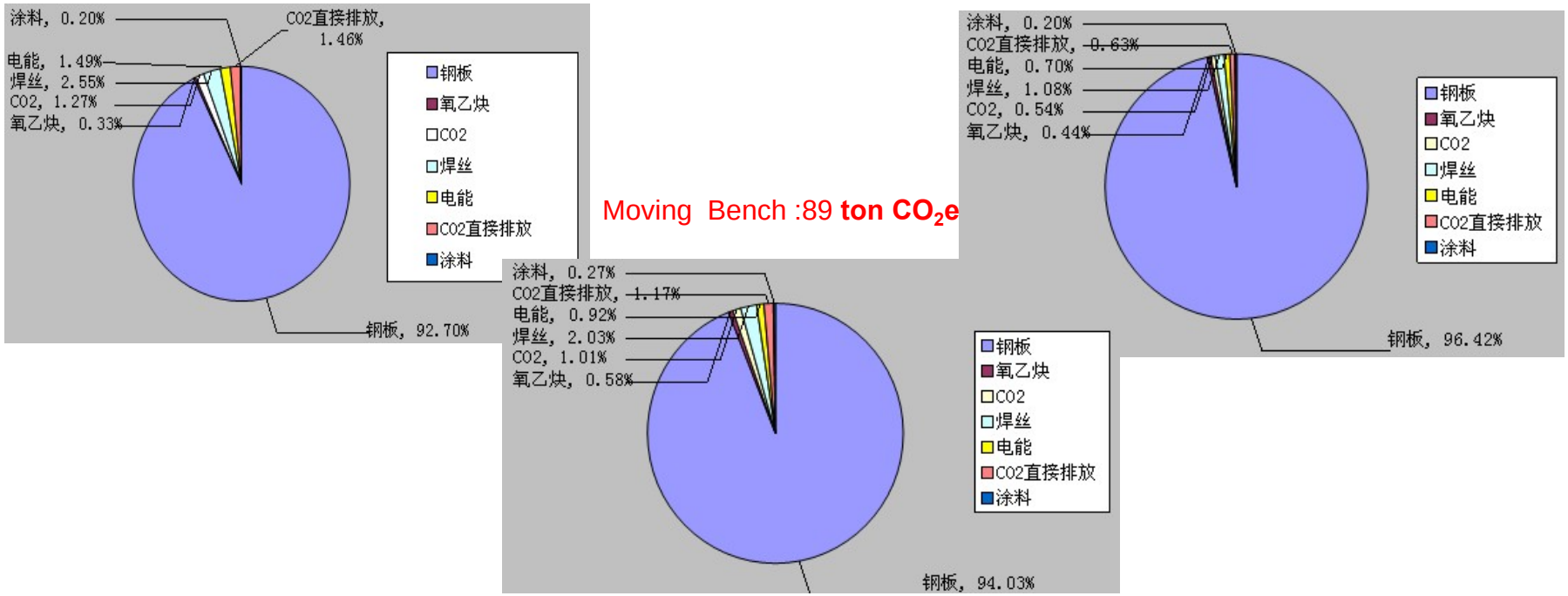
Our works

A CASE: For a 2000 ton hydraulic press, we analyzed the carbon emissions during its frame manufacturing (including: upper beam, lower beam and moving bench).

Upper Beam:**152 ton CO_2e**

Lower beam:175 ton CO_2e

Moving Bench :89 **ton CO_2e**

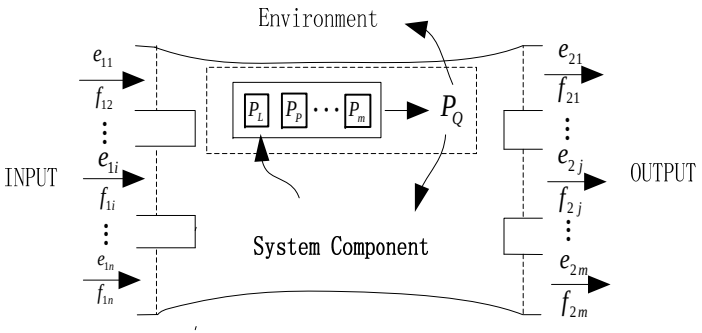


Carbon emissions of 2000 t hydraulic press machine

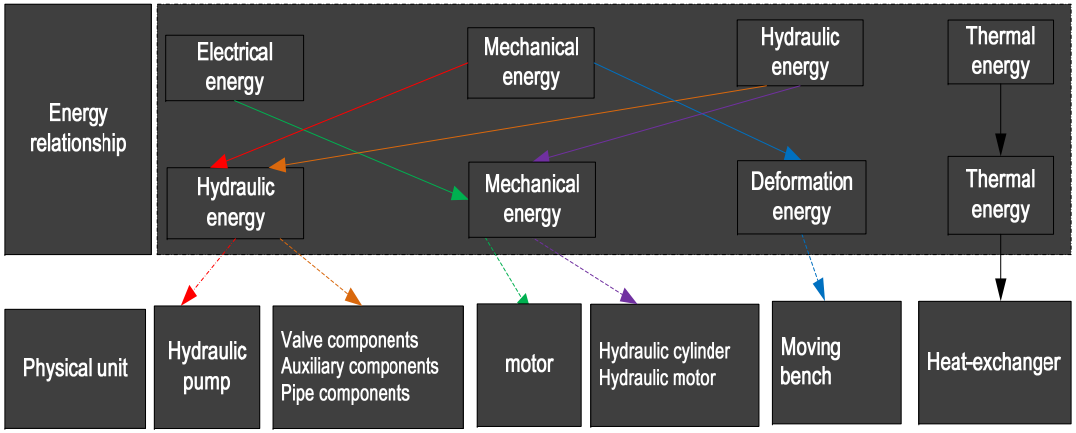
- **Steel consumption is the biggest contributors to the carbon emissions: ~80%**
- **Welding is the critical process contributing to the carbon emissions.**

Our works

◆ Energy flow and energy loss during service of the forming machine



Analysis of energy in System Component



classification of hydraulic press system

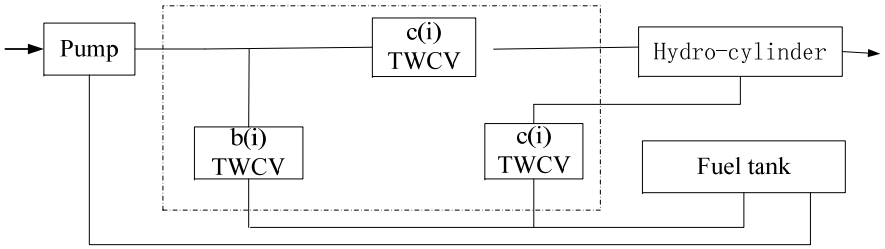
"E-M" units: $P^{w}_{E-M}(\beta, c) = P^{w}_{Fe} + P^{w}_{fw} + P^{w}_{Cu1} + P^{w}_{Cu2} + P^{w}_{stray}$

"M-H" units: $P^{w}_{M-H}(p,n,c) = P^{w}_{mec} + P^{w}_{vol}$

"H-H" units: $P^{W}_{H-H}(q,c) = P^{w}_{l} + P^{w}_{f}$

"H-M" units: $p^{w}_{H-M}(p,p',v,F) = P^{w}_{mec} + P^{w}_{vol}$

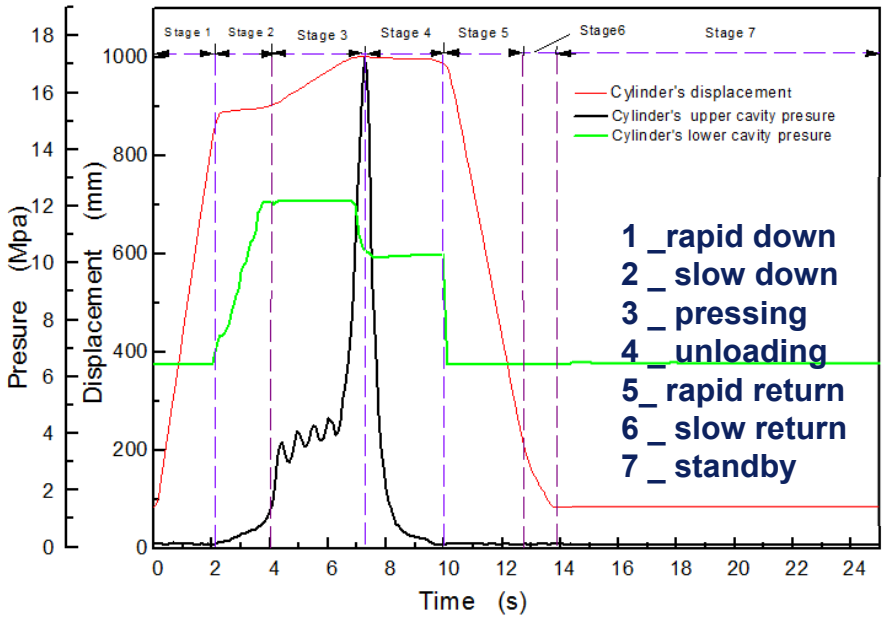
"M-D" units: $P_{\text{metal forming}}(F,v) = P_{d} + P^{w}_{f}$



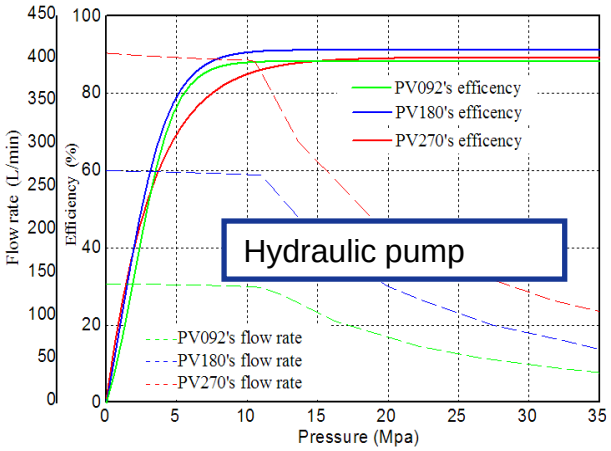
Simplification of hydraulic press control valve group

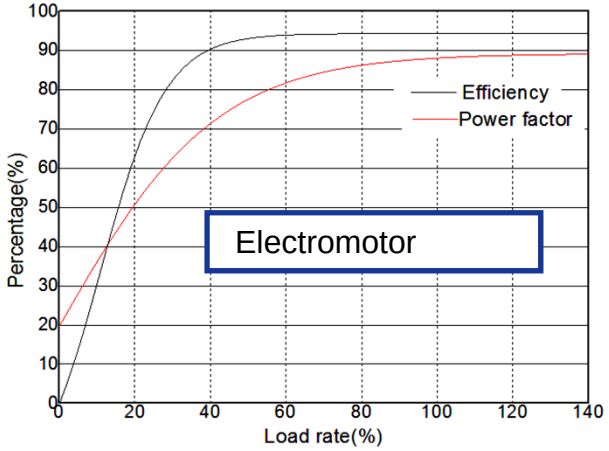
$$E^{c-active} = \sum_{i=1}^{r}\left(\sum_{j_1=1}^{m} E^{w}_{i-j_1-motor} + \sum_{j_2=1}^{n} E^{w}_{i-j_2-pump} + \sum_{j_3=0}^{s(i)} E^{w}_{i-j_3-twcv} + \sum_{j_4=1}^{r(i)} E^{w}_{i-j_4-pipe} + \sum_{j_5=1}^{k(i)} E^{w}_{i-j_5-cylinder}\right) + E_{\text{metal forming}}$$

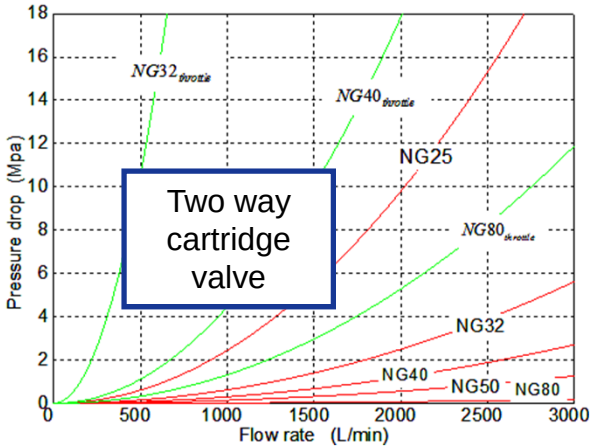
Our works



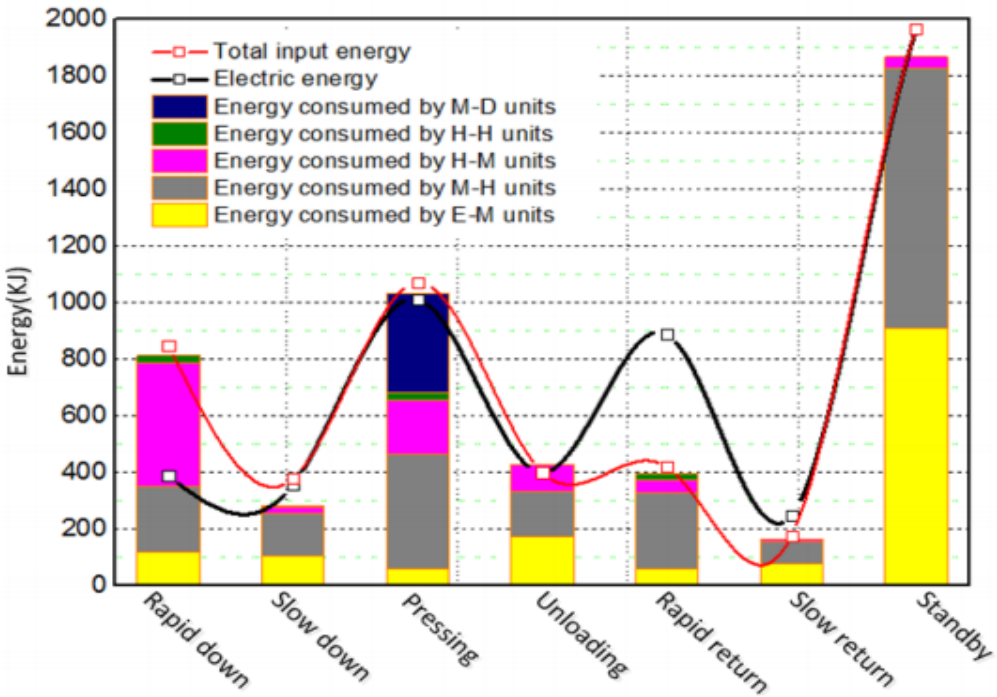
A case: The 2000-ton hydraulic press



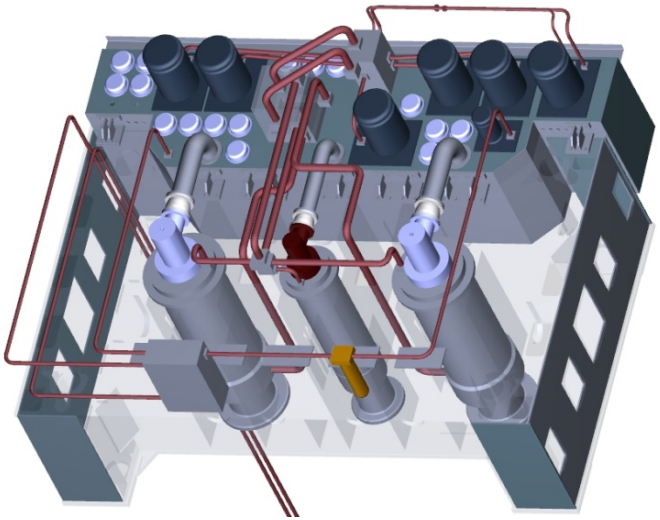


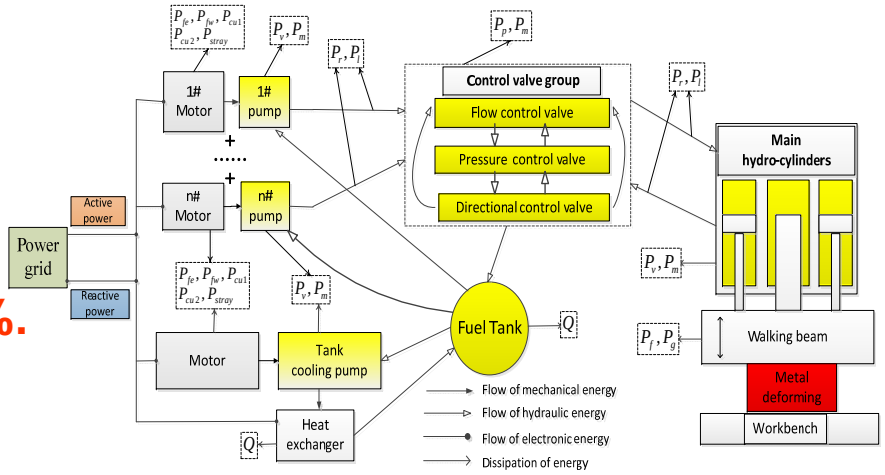


Our works



Total energy dissipation





The energy flow of the hydraulic press system

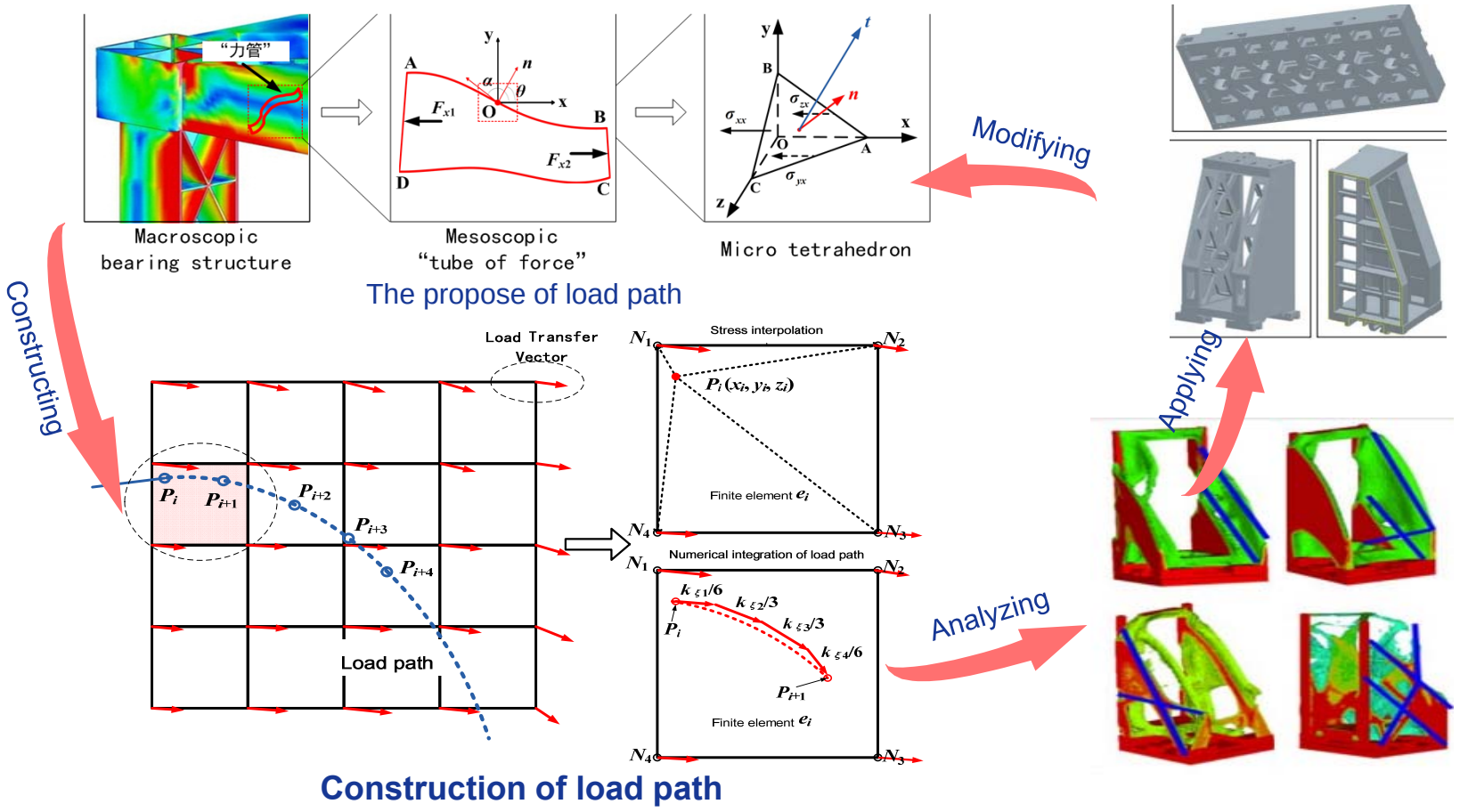
Energy Efficiency of the machine is **only 7.1%.**

- **Electrical-mechanical: 70.35%**
- **Mechanical-hydraulic: 37.43%.**
- **Hydraulic-deformation: 27%.**

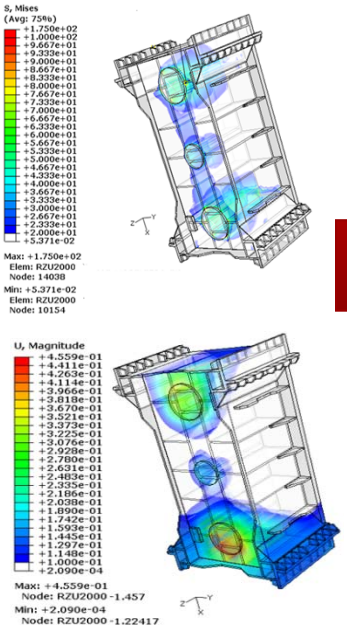
The Reason: load characteristic and driving mode does not match the required load.

Our works

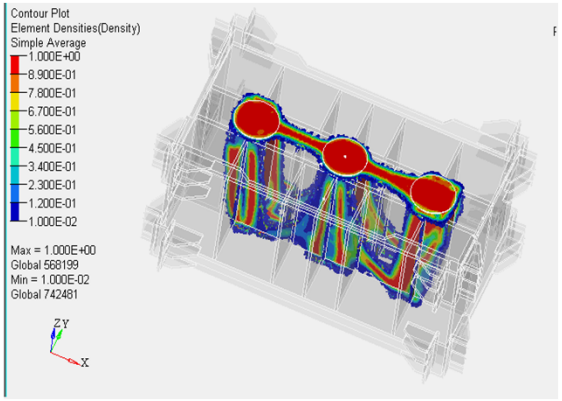
- **The innovative structure design and material-saving design based on the concept of load path**
  - load path



Our works

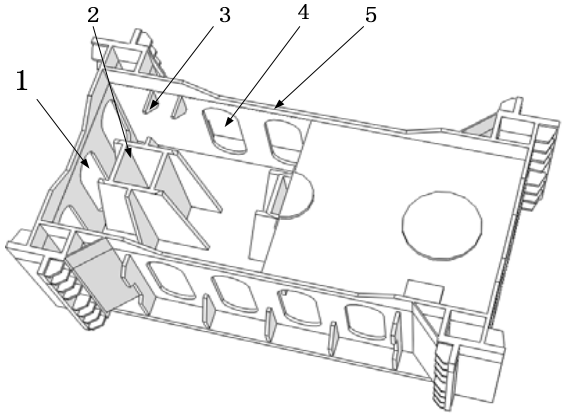


FE Model



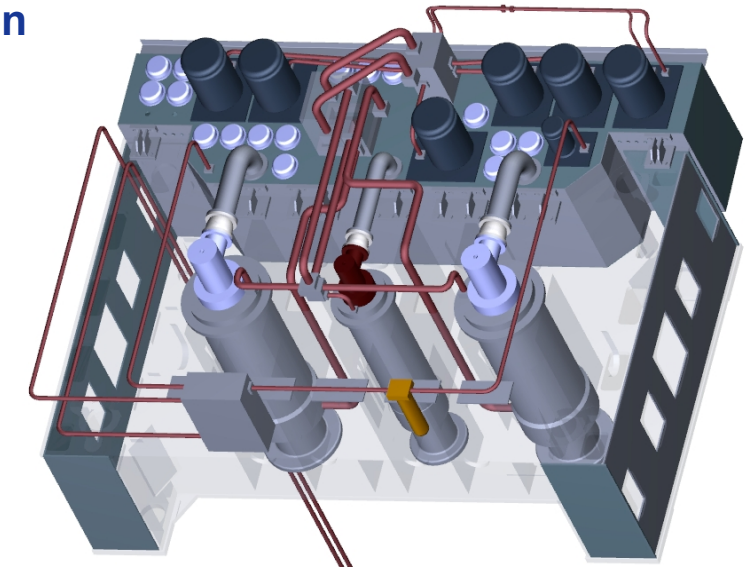
Low carbon design Optimization

- Material saving
- Energy flow optimization



Re-design

Structure optimization and Redesign of the forming machine

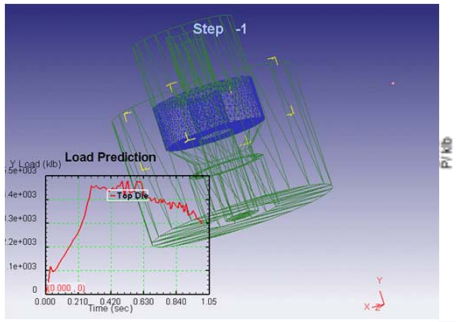


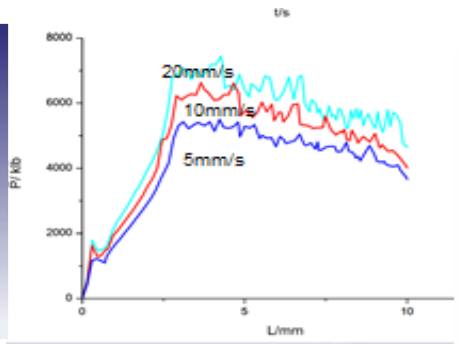
The structure of hydraulic system

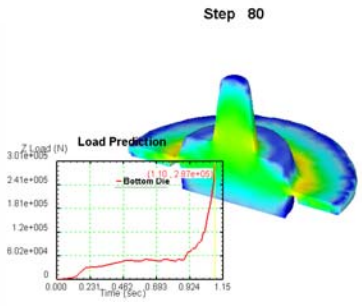
Our works

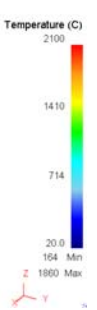
◆ Forming processes VS. energy dissipation of forming machine

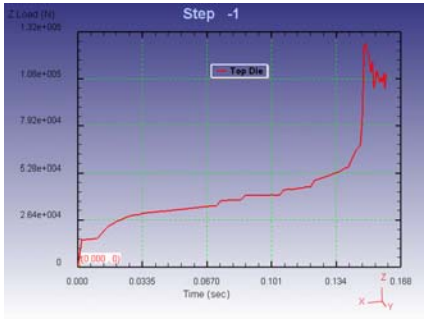
In order to build the database of energy consumption of the metal forming processes, the mapping relationships between energy consumption and typical metal forming process parameters have been investigated, including: hot extrusion, roulette open die forging, u-shaped bending, and Hemisphere-shaped drawing craft.





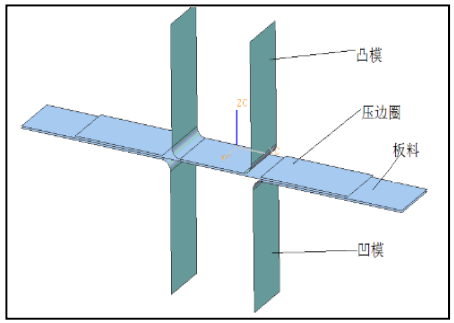


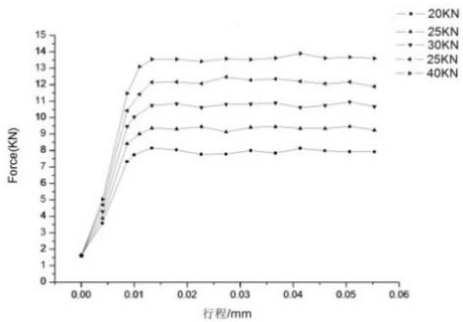




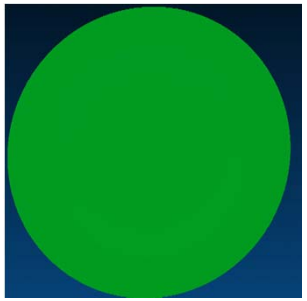
Hot extrusion

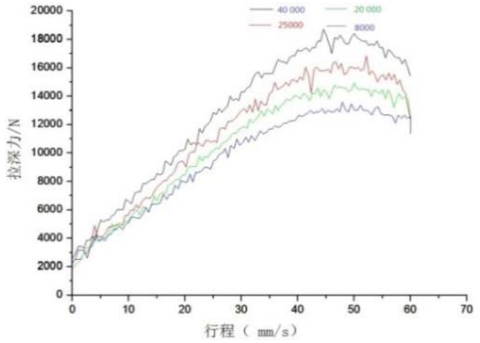
Roulette open die forging





U-shaped bending



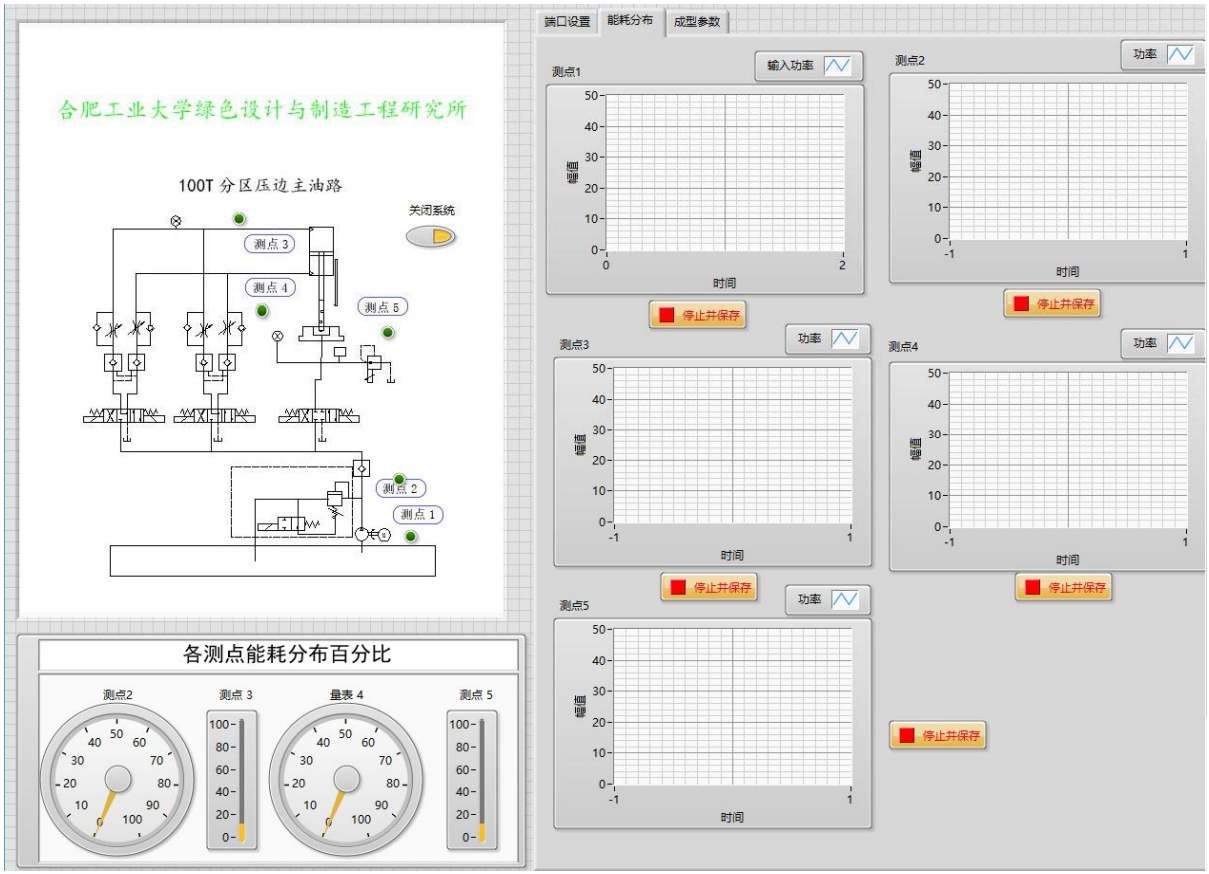


Hemisphere –shaped drawing craft

Our works

◆ Building a low-carbon manufacturing test platform

Based on test platform, the real-time measurement of the blank holder force, the pressure and displacement of main cylinder, electrical energy consumed in metal forming processes can be acquired, to make the energy flow visible as possible.



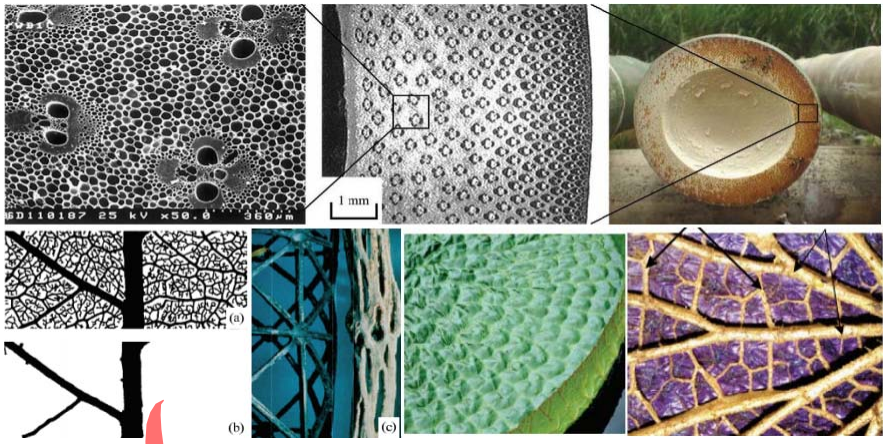
Possible Future Works

- To identify, characterize, and control the redundant energy of the metal forming machines and other machine tools.
- Low carbon design and process optimization for large metal forming machines.
- The carbon emission database of forming processes and other machining processes.
- The uncertainties in the lifecycle carbon footprint analysis.
- And finally, a new design method for the metal forming machines.

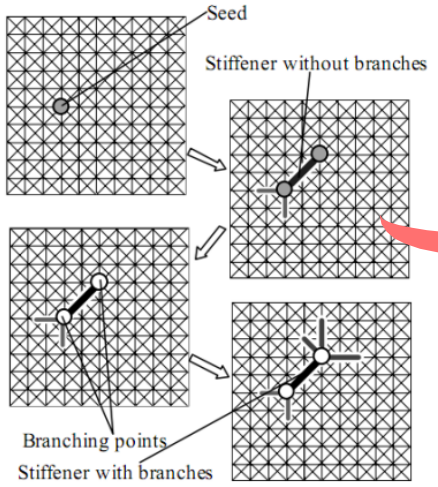
The ULTIMATE GOAL is to change traditional requirement of stiffness and power!

Possible Future Works

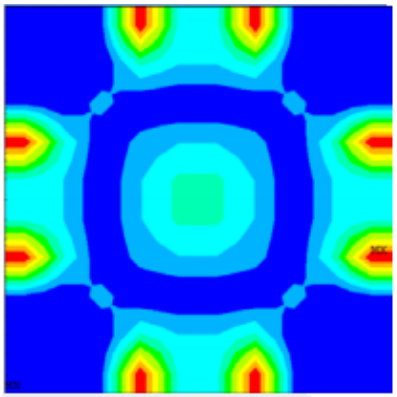
A new structure design method: adaptive material adding design method based on the concept of load path so as to achieve the most reasonable distribution of materials – an ongoing work.



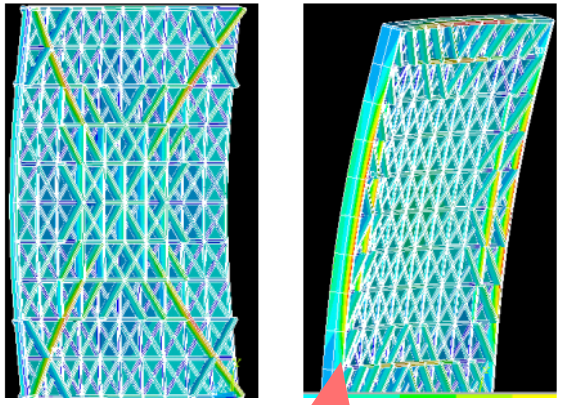
Bionic research

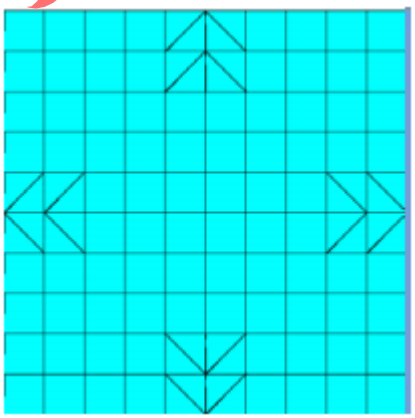


Modeling



Simulating





Thanks for Your Attention!

Backup

Research Teams

- Some of low-carbon design and manufacturing research teams

The Centre for Sustainable Design
University of British creative arts

Manufacturing and Productivity Lab
Massachusetts Institute of Technology

Green Design Institute
Carnegie Mellon University

Institute of Advanced Industrial
Science and Technology

Sustainable Design and Manufacturing
Union of Technical University of Georgia

Green Design and Manufacturing Union
University of California

Life Cycle Engineering
University of Stuttgart

Institute for Sustainable Manufacturing
University of Kentucky

Gerry Sano Institute for Sustainable
Rochester Institute of Technology

Flemish Institute of Technology

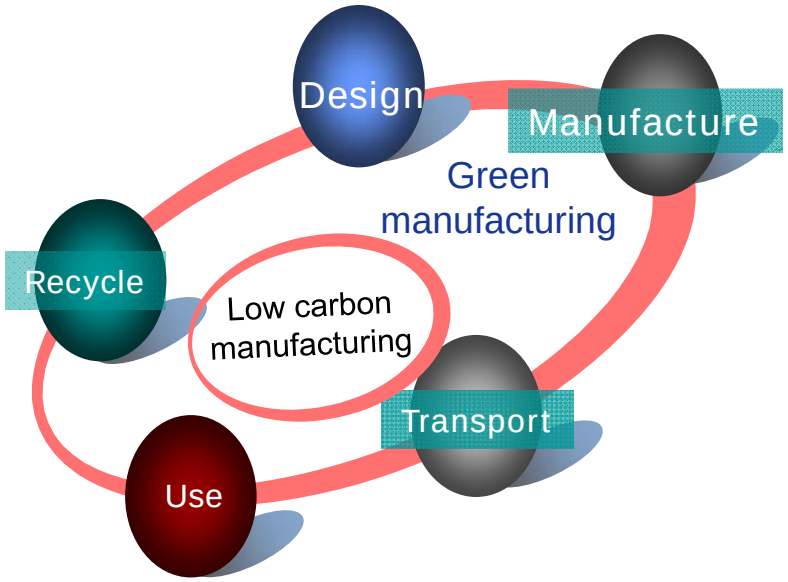
Definitions

- **Low-carbon manufacturing & energy saving, material saving, emissions reducing**

  Low-carbon manufacturing is the integrative optimization of resources, energy, and carbon emissions in the entire product life cycle, based on the life-cycle carbon footprint.

- **Low-carbon manufacturing & green manufacturing**

  Low-carbon manufacturing is derived from the green manufacturing under the background of low-carbon economy to wrestle with the challenges of "energy crisis" and "greenhouse effect."



- **Architecture of low-carbon manufacturing**

  Low-carbon product design, Manufacturing system's optimization, low-carbon resource development.

Definitions

Framework

Low-carbon Product design

1) Less carbon emissions in material production process, high recovery rate, allocation of structures and components;
2) Meet different needs by optimizing the combination of different function modules;
3) Good functional scalability, high energy efficiency and few emissions in use.
4) Suitable manufacturing technology, fewer secondary resources;
5) Easy and quick disassembly, low remanufacturing cost, high yield .

Manufacturing system optimization

1) Efficient processing machine, properly used of auxiliary components;
2) Advanced processing technology, less auxiliary materials and waste, short air travel time ;
3) Efficient production mode, scientific production scheduling.

Low-carbon resource development

1) Develop green materials that can be recycled ;
2) Reduce the proportion of fossil energy use, improve the proportion of clean energy use.

Our works

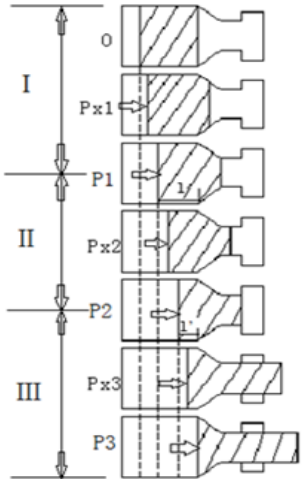
- **The mapping relationships between energy consumption and process parameters for typical metal forming processes.**

Hot extrusion craft

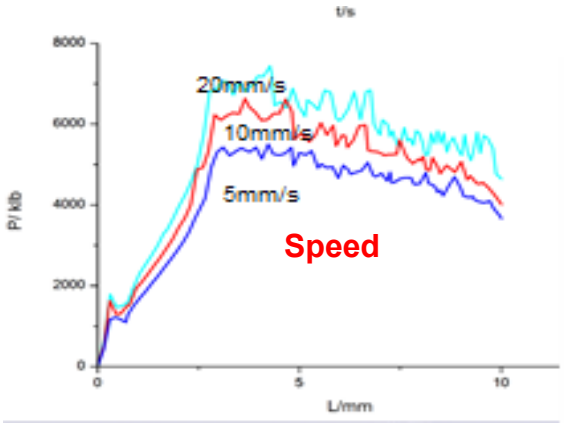
Begin to extruding

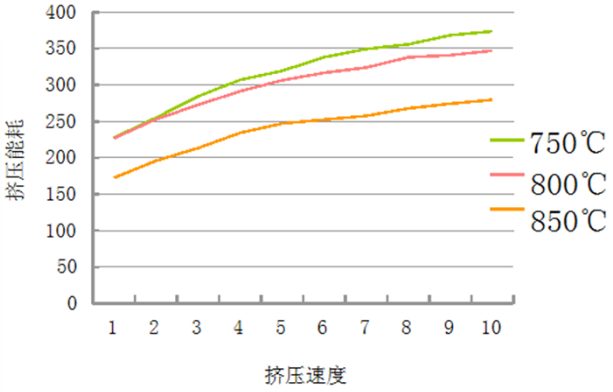
Fill with billets

Billets pass through



Extrusion process



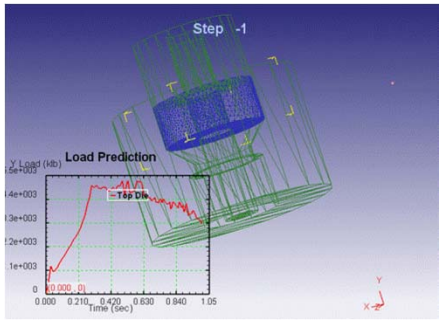


Forming force and energy analysis of hot extrusion

$$P_1 = \sigma_s (R_3^2 - R_0^2)\pi[(1+\mu\csc\alpha)\ln\lambda + \mu\cot\alpha\,|\ln\frac{(R_3-R_0)^2}{\lambda(R_1-R_0)^2}| + \frac{2\mu l}{R_3-R_0}]$$

$$P_2 = \sigma_s (R_3^2 - R_0^2)\pi[(1+\mu\csc\alpha)\ln\lambda + \mu\cot\alpha\,|\ln\frac{(R_3-R_0)^2}{\lambda(R_1-R_0)^2}| + \frac{2\mu l_{工作带}}{R_1-R_0} + \frac{2\mu l'}{R_3-R_0}]$$

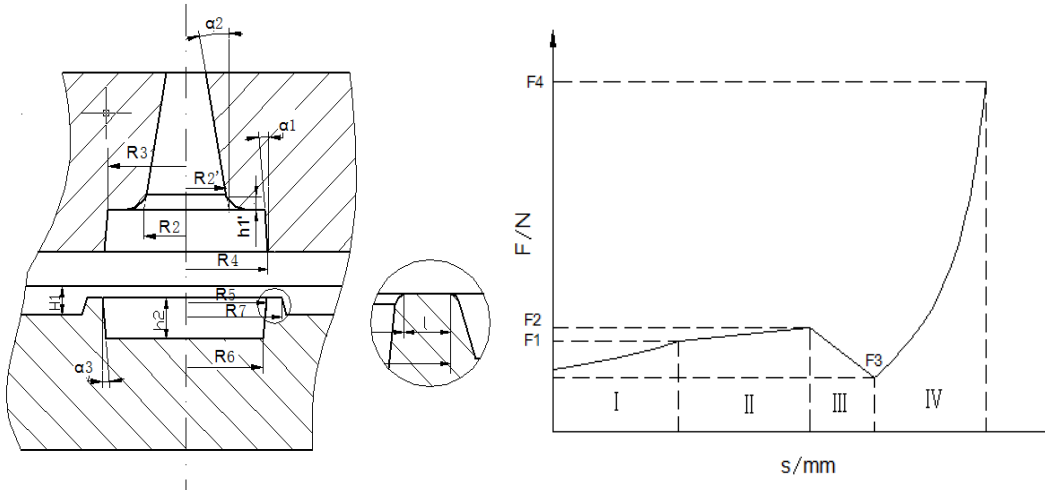
$$P_3 = \sigma_s (R_3^2 - R_0^2)\pi[(1+\mu\csc\alpha)\ln\lambda + \mu\cot\alpha\,|\ln\frac{(R_3-R_0)^2}{\lambda(R_1-R_0)^2}| + \frac{2\mu l_{工作带}}{R_1 - R_0}]$$



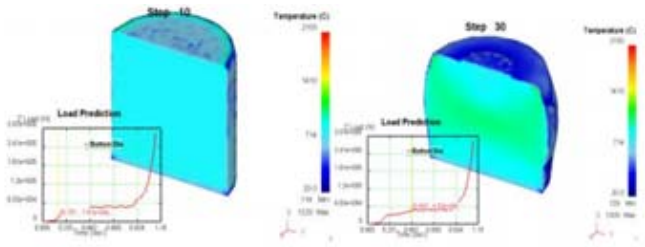
Simulation of metal flow in hot extrusion process

Our works

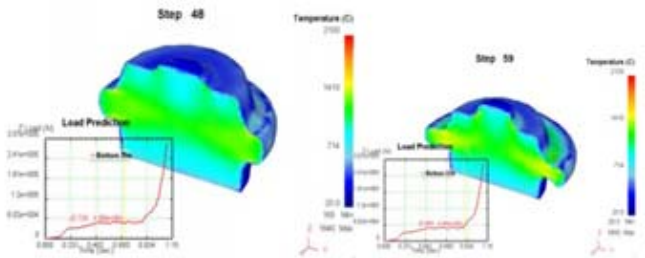
➢ Roulette open die forging craft



Roulette open molds and forming force-displacement curve



Pure upsetting

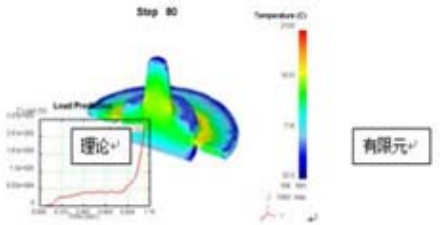


Hybrid of upsetting and extruding

$$E = \int_0^{a_1} [\frac{\pi}{4}\sigma_s d^2(1+\frac{\mu}{6}\frac{d}{H-s})]ds + \frac{\pi}{8}\sigma_s d^2[(\frac{m'}{R_0^2}+h_{飞})(1+\frac{\mu}{6}\frac{d}{h_1-h_2+h_{飞}}) - (\frac{m}{[R_0+(1+$$

$$+h_{飞})(1+\frac{\mu}{6}\frac{d}{h_1-h_2-\frac{m_1}{R_0^2}})] - \frac{1}{2}\frac{m_2}{[R_0+(1+\frac{H_1}{h})l]^2}\{\pi R_4^2\sigma_s[(1+\mu\csc(\frac{\pi}{2}-\alpha_1))\ln\lambda_1$$

$$+(1+\mu\csc(\frac{\pi}{2}-\alpha_2))\ln\lambda_2] + \frac{l}{h}\pi\sigma_s(R_7^2-R_5^2) + \frac{l}{H_1}\pi\sigma_s(R^2-R_7^2)\}$$



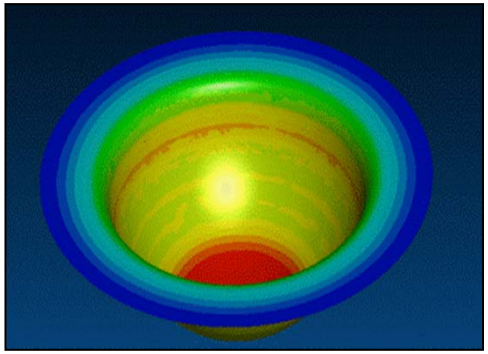
Pure extruding

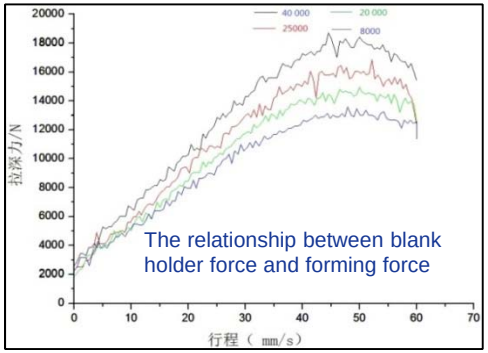
Our works

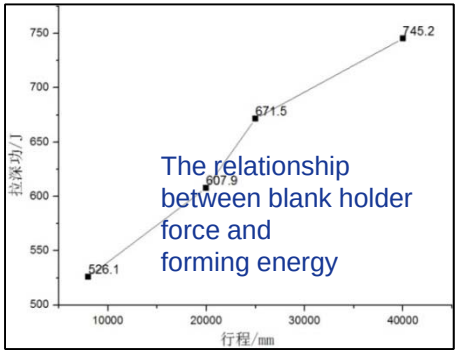
- Sheet metal forming process

The principal stress method is adopted to research on hemispherical drawing, u-shaped bending . When all the effect of blank holder force, friction and bending are considered together, the theoretical calculation model of forces acting with the variation of displacement during the deep drawing process is obtained .

Hemisphere Shaped pieces Drawing Craft







U-shaped Bending craft