The Fundamental Research on Remanufacturing in China

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Contents

1. Introduction
2. Research Status & Challenges
3. Remanufacturing progress in the Research Center for Sustainable Manufacturing of Shandong University
4. Outlook
1. Introduction
Dilemma Situation of ME Manufacturing Industry in China

Mechanical Equipment (ME) Manufacturing Industry is the Backbone of Nations Economy

Nationwide total industrial output value in 2010 is 70 trillion, ME mfg. output value almost 21 trillion (taking 30%)

The market demanding is rising

Output Value
- Machine Tool Industry 530 billion
- Engineering Machinery 400 billion

Sales Volume
- Heavy Truck 1.01 million
- Motor Vehicle 18 million
Shortage of Natural Resource — Bottleneck of the Sustainable Development of Manufacturing Industry

Major raw materials in ME Manufacturing Industry: Copper, Iron, Aluminum critical shortage worldwide, but these reserves percent in China is only 5%, 13.1%, 4.1%

Supplying ages of Copper, Iron, Aluminum in China are only 4 years, 14 years, 12.5 years!
Dilemma Situation of ME Manufacturing Industry in China (Con.2)

Pressure of Energy Conservation and Emissions Reduction

Mechanical Equipment ownership:
- Engineering Machinery ownership the world’s #1!
- Vehicle ownership the world’s #2!

Ownerships in 2011

- Construction Machines 5 million
- Vehicle 9.35 million
- Heavy Truck 5 million
- Machine Tools more than 8 million

Obsoleted ME products
— — Where to go?

Scrap smelting?

Secondary funding input!
Secondary environment pollution!
Secondary energy consumption!
Dilemma Situation of ME Manufacturing Industry in China (Con.3)

- Backbone of Nations Economy
- Shortages of Natural Resources
- Pressures of Energy Conservation and Emission Reduction

If we pursue the sustainable development, then the original concepts of manufacturing should be changed!
ReMan is one of the key solutions!

- **Remanufacturing**: is the industrialization of obsoleted product restoration by using contemporary technologies.

- **Remanufacturing**: The quality and functionality of reman product is not lower than new ones, sometimes even higher.

A roughly case analysis of a heavy duty diesel engine.
Phase 1: Remanufacturing industry initiation stage (In the early 1990s - 2001)

Since the early 1990s, there are appeared some remanufacturing enterprises in China, such as Sinotruk Jinan Fuqiang Power Co., Ltd. Sino-British joint venture, Remanufacturing Branch of Shanghai VOLKSWAGEN Powertrain CO., LTD. (Sino-German joint venture).

Jinan Fuqiang and its remanufactured diesel engine
### Phase 2: Academic studies and scientific research demonstration stage
(June, 1999 - December 2006)

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999.06</td>
<td>Scholar first presented the concept of &quot;remanufacturing&quot; in the Chinese academics, at Xi’an international conference.</td>
</tr>
<tr>
<td>2001.05</td>
<td>The first national key laboratory (National Science Key Lab of Equipment Remanufacturing) in the remanufacturing field was built.</td>
</tr>
<tr>
<td>2002.09</td>
<td>Two major projects about remanufacturing basic theory and key technology research were approved by National Natural Science Foundation.</td>
</tr>
<tr>
<td>2003.08</td>
<td>“Selfreparing and Remanufacturing of Mechanized Equipment” was listed as one of the 19 key technologies by the &lt;Manufacturing development science studies&gt;</td>
</tr>
<tr>
<td>2006.12</td>
<td>Mechanical and electronic products recycling and remanufacturing was listed as one of the 17 Saving-oriented society priority project by The consulting report of CAE (the Chinese Academy of Engineering)</td>
</tr>
</tbody>
</table>
In 2005, “the notice about the circular economy pilot carried out” was issued by GOC (the government of China), and remanufacturing was listed as one of four key areas.

In May, 2005, <Opinion of promoting the development of remanufacturing industry> made remanufacturing industry as new economic growth point.

In 2008, 14 companies were listed as pilot enterprises auto parts remanufacturing industry by NDRC(National Development and Reform Commission).

The circulate economic propel law was taken effect, and it marked that the remanufacturing had entered the national laws.

In 2013, The remanufactured product would be increased subsidies and popularization, which was written in < The implementation scheme of “old for remanufactured products” >
2. Research Status & Challenges
Disassembling of remanufacturing objects

Application status

Remanufacturing disassembling is to orderly and regularly disassemble the equipment and its components into all separate parts.

At present, the main method of disassembly is manual dismantling with tools and equipments, and the ways includes knocking, drawing, extruding, temperature differential method and destruction.

Wrenches used in disassembling
Disassembling of remanufacturing objects (Con.1)

Research Status

① Disassembly model research—The generation of old equipment dismantling depth, disassembly model and disassembly sequence will be researched, by virtual disassembly and clean disassembly concept. Then disassembly model will be formed accurately, and environmental pollution and energy consumption will be reduced during the process of dismantling.

② Developing automatic and dismantling of equipment for remanufacturing disassembly.

③ The interface damage of big interference fit disassemble mechanism and temperature differential disassembly.（From the 973 project）

The big interference fit contact analysis

Nondestructive disassembly experiment table
## Cleaning technology for remanufacturing object

### Application status

<table>
<thead>
<tr>
<th>Cleaning method</th>
<th>Chemical cleaning</th>
<th>Leaching</th>
<th>Sandblasting Cleaning</th>
<th>High pressure jet cleaning</th>
<th>Electrolysis Cleaning</th>
<th>Dry ice cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages and disadvantages</td>
<td>Widely used, high efficiency, high environmental impact</td>
<td>Small consumptio n, small washing power, for rinsing</td>
<td>Thorough cleaning, widely used, low-cost, noise, dust, solid waste</td>
<td>For cleaning flammable, explosive, toxic and radioactive substances; cleaning effect, high efficiency, low cost of energy</td>
<td>Suitable for degreasing rust, more thorough, secondary chemical and physical cleaning</td>
<td>Fast, thorough, you can quickly remove the soft cover, non-toxic, high cost</td>
</tr>
</tbody>
</table>

![Electrolytic cleaning](image1)

![Molten salt cleaning](image2)

![High pressure cleaning system](image3)

![Ultrasonic water cleaning](image4)

Electrolytic cleaning

Molten salt cleaning

High pressure cleaning system

Ultrasonic water cleaning
Cleaning technology for remanufacturing object (Con.1)

Research Status

Ultrasonic - super / sub-critical CO₂ fluid composite cleaning

- contamination layer removal mechanism
- influence of process parameters to the removal of the contaminated layer

Wet blast cleaning

Ultrasonic molten salt Composite cleaning

- Ultrasonic cleaning
  - Vibration frequency
  - Power density
  - Uniformity of the sound field
- Molten salt cleaning
  - Security
  - Reduction in hydrogen evolution
  - Molten salt penetration mechanism
  - Cleaning temperature
  - Process time
  - Green medium proportion
  - Clean production
  - Activation law of active particles
  - Process after cleaning
Nondestructive examination and remanufacturability judgment

Application status

There are many Non-destructive testing means in the enterprise, such as magnetic, permeability, ultrasonic, eddy current, infrared, X-ray detection, acoustic emission, etc. But these methods have a low rate for invisible defect detection, and it’s unable to provide an accurate defect size for life assessment. The assessment of recycled products’ remaining life and value entirely depend on the experience.
Nondestructive examination and remanufacturability judgment (Con.1)

Research Status

① By using multi-parameter detection technology and systems, such as nonlinear ultrasound, ultrasound phased array, ultrasonic excitation infrared detectors, metal magnetic memory testing and so on, the micro-defects and micro-damage of remanufacturing object’s surface and internal can be accurately detected.
② Competitive life research based on the surface and internal damage.
③ Depending on the damage, remaining life, repair process, environment, cost and other factors, multidimensional remanufacturability judgment model can be established based on technical, economic and environmental.
Remeanufacturing repair technology

Application status

The main technical includes brush plating technology, thermal spraying technology, plasma arc cladding technology, laser cladding technology, welding technology.
Research Status

Pulse electron beam crack repair technology

Microhardness (HK) vs. Number of pulses for 23.4kv and 27kv.

23.4kv-25 board strips martensite of subsurface Metallographic.
Remanufacturing repair technology (Con.2)

Research Status

Laser cladding material matching of remanufacturing method.

The spraying material matching of remanufacturing method

<table>
<thead>
<tr>
<th>Technical indicators</th>
<th>America SHS7170</th>
<th>America 100MXC</th>
<th>Domestic reports Silk material</th>
<th>FeBSiNb Silk material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amorphous content</td>
<td>70%</td>
<td>Nano-structures</td>
<td>55.3%</td>
<td>≥80%</td>
</tr>
<tr>
<td>porosity</td>
<td>3.0%</td>
<td>2%</td>
<td>2.3%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Bonding strength</td>
<td>44.5 MPa</td>
<td>35-48 MPa</td>
<td>—</td>
<td>57.4 MPa</td>
</tr>
</tbody>
</table>

Multilayer cladding layer microstructure of FeCrBSiNiCrMo powder
- Compact structure
- No macroscopic defects

Develop material goals
Remanufacturing repair technology (Con.3)

Research Status

Temperature field and stress field analysis in laser remanufacturing forming process

- Finite element model of laser remanufacturing
- Mapping relationship between temperature field and metallurgical structure
- The metallurgical structure and performance control of the laser remanufacturing parts

High precision and lower stress machining

- Research on the milling performance of laser cladding repair layer;
- Analyze the influence of milling parameter to milling vibration acceleration, milling force, and surface quality, improve surface quality and material removal rate.

Simulation of laser cladding

Surface topography after milling

Ra=249.8μm

Ra=524.2μm

Ra=859.6μm

Ra=645.4μm
Life assessment of repaired compressor impeller

Study of simulation life

New impeller simulation
- Basic dynamic analysis
- Rotating stall failure analysis
- Wake excitation failure analysis

Can’t get simulation life of the new impeller

Viable simulation life theory and method for remanufactured impeller

Remanufactured impeller simulation

Secondary service life:

\[ N = (N_{tot} - N_e) \times K_{r_e} = 5.82 \text{ (years)} \]
New impeller simulation life

Remanufactured impeller simulation life

Study of theoretical life

Validating service life

Study of simulation life

New impeller has been carried out conventional tension and compression fatigue test of the standard test blocks (σ_m = 0). Estimate H418 impeller theoretical life at different stress levels.

We carried out conventional tension and compression of Remanufacted impeller standard test block, high-cycle fatigue bending test and the approximate frequency blade high cycle fatigue test for the model.
Life assessment of repaired compressor impeller

Study of simulation life
- Remanufactured impeller
- Nondestructive Testing
  - Using super-heavy drum test bench, assess strength of the Remanufactured impeller, like the new impeller test
- Conventional coloring
  - Metal magnetic memory
  - Nonlinear ultrasound
- Carrying out higher NDT standard than new impeller

Study of theoretical life
- Ultra-turn assessment
- Nondestructive Testing
  - Using SBW φ200 opened impeller and φ450 closed impeller model-level test bench, assess Remanufactured impeller fluid and mechanical properties.

Validating service life
## Challenges

<table>
<thead>
<tr>
<th>Remanufacturing technology</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Disassembly</strong></td>
<td>① Low automation, Labor-intensive process: low efficiency, high cost and long period.  ② <strong>Guarantee the quality after assembling</strong> for the parts with big interference and high added-value.</td>
</tr>
<tr>
<td><strong>Remanufacturability judgment</strong></td>
<td>① Identification and quantification of small-scale damage  ② Unified evaluation standard for diversity and competition of damage</td>
</tr>
<tr>
<td><strong>Cleaning technology</strong></td>
<td>① Coordination of energy saving, environmental, economical, efficient, no damage</td>
</tr>
<tr>
<td><strong>Repair technology</strong></td>
<td>① Precise control of the high energy beam (smaller deformation and smaller stress)  ② Low stress machining of repairing layer</td>
</tr>
</tbody>
</table>
3. Remanufacturing in the Research Center for Sustainable Manufacturing of Shandong university
Brief Introduction

SMRC

- Professor
- Lecturer
- Postdoctoral
- Doctor
- Master

Green product design
Biomass products
Green machining technology
Remanufacturing technology

Page 28
11/5/2014
Prof. Li Jianfeng, Prof. Li Fangyi.
School of Mechanical Engineering, Shandong University
## Brief Introduction of Research

<table>
<thead>
<tr>
<th>Remanufacturing technology</th>
<th>Green machining technology</th>
<th>Green product design</th>
<th>Biomass products</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Nondestructive examination</td>
<td>• Machining of hard-to-cut material</td>
<td>• Life cycle assessment (LCA)</td>
<td>• Biomass meal-box</td>
</tr>
<tr>
<td>• Remanufacturability judgment</td>
<td>• Green Cutting processing</td>
<td>• Light weight design</td>
<td>• Biomass cushioning package</td>
</tr>
<tr>
<td>• Cleaning technology</td>
<td>• Machine tool design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Remanufacturing repair technology</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Nondestructive examination
- Remanufacturability judgment
- Cleaning technology
- Remanufacturing repair technology
- Machining of hard-to-cut material
- Green Cutting processing
- Machine tool design
- Life cycle assessment (LCA)
- Light weight design
- Biomass meal-box
- Biomass cushioning package
**Brief Introduction--Projects**

<table>
<thead>
<tr>
<th>Research Projects</th>
<th>Project source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trans-scale damage evolution for remanufacturing objects and judgment theory of the remanufacturability (2011-2016, total 32 millions. Sub 5.2 millions, SDU)</td>
<td>National Basic Research Program of China (973 Program)</td>
</tr>
<tr>
<td>Remanufacturing rough part bonding / fitting mechanism and implementation (Sub 1 million, by SDU)</td>
<td></td>
</tr>
<tr>
<td>Study of recycling system of engineering machinery product and the key technology of reverse logistics</td>
<td>National High Technology Research and Development Program of China (863 Program)</td>
</tr>
<tr>
<td>Researches on green technology assessment for machine tool and construction machinery, and development of related databases for mechanical products.</td>
<td></td>
</tr>
<tr>
<td>The preparation and mechanical properties of biomass cushion packaging materials</td>
<td>National Natural Science Foundation of China</td>
</tr>
<tr>
<td>Modeling of product design scheme based on green features</td>
<td></td>
</tr>
<tr>
<td>Mechanism and application of Composite cleaning of ultrasonic and Molten Salt</td>
<td></td>
</tr>
<tr>
<td>Study on the forming mechanism of compatibility of biodegradable biomass cushion packaging product</td>
<td>Innovation Fund of Shandong University</td>
</tr>
</tbody>
</table>
(1) The ultra-high cycle s-n curve of impeller material \textit{FV520B}, \textit{KMN} is obtained for the first time (enterprise urgently needed), providing the material data base for the life estimation of old impeller and design of new impeller; The estimation model of existing high cycle fatigue strength and fatigue life is corrected, providing the base for the selection of impeller fatigue damage model.

The ultra-high weeks s-n curve of impeller material \textit{FV520B}
(2) The erosion mechanism of FV520B is analyzed (micro cutting, deformation wear). The erosion model related to the factors such as particle properties and erosion environment are established.

- Theory basis: Erosion wear are divided into deformation wear and micro cutting wear, they are the function of velocity and tangential velocity.
- Methods: assuming spherical particles impact, solving the equation of particle motion and the collision energy equation, introduce particle shape index to the calculation.

\[
\varepsilon = \frac{A \rho_p^{1/4b} V^{2+1/2b} (\sin \alpha)^{2+1/2b}}{H_V^{1+1/4b} \varepsilon_c^{1/b}} + \frac{B d_p^{2(1-g)} \rho_p^{3(1-g)/4} V^{2+3(1-g)/2} (\sin \alpha)^{3(1-g)/2} (\cos \alpha)^2}{H_V^{3(1-g)/4} P_t}
\]

- \(\varepsilon\) —— quality erosion rate
- \(A, B\) —— is the constant coefficient;
- \(\rho_p\) —— grain density.
- \(V\) —— impact velocity;
- \(d_p\) —— grain diameter
- \(\alpha\) —— the impact Angle;
- \(H_V\) —— the Vickers hardness of target;
- \(\varepsilon_c\) —— the critical strain of material when it is flaked;
- \(g\) —— particle tip shape index;
- \(P_t\) —— material flow stress.

The calculation results of erosion rate under different impact angles compared with the test results.
(3) In the FV520B impeller’s actual service environment, the stress corrosion mechanism in the medium containing $H_2S/CO_2$ is transgranular hydrogen induced cracking;

With the increasing of concentration of $H_2S$, materials' stress corrosion sensitivity increased gradually; When temperature is 70℃ and medium concentration is 65% $CO_2$ and 30% $H_2S$, FV520B has the highest stress corrosion sensitivity, which provides the foundations for the subsequent study of life of crack propagation.

![The fracture and side morphology under the different temperature](image1)

![The slow tensile test curve under different conditions](image2)
(4) In the range of ultra-high cycle fatigue, the fatigue damages caused by the internal inclusion and surface defect compete with each other. According to the equivalence principle of fatigue strength, first calculate the equivalent critical dimension of the surface roughness, as well as the internal inclusion critical dimension, and then following the next conditions to determine the fatigue life of the material so as to lay a theoretical foundation for the confirmation of remanufacturing critical threshold value.

![Failure analysis of the competition between internal inclusion and surface defect](image)

1. when $\sqrt{A_R} < \sqrt{A_{R,c}}$, fatigue failure depends on the size of the internal inclusion, estimate the critical threshold value as curve II.
2. when $\sqrt{A_R} > \sqrt{A_{R,c}}$:
   1. If $\sqrt{A_{in}} < \sqrt{A_{in,c}}$, fatigue failure depends on the size of surface roughness, estimate the critical threshold value as curve I.
   2. If $\sqrt{A_{in}} > \sqrt{A_{in,c}}$, fatigue failure depends on the fatigue strength which is corresponded with internal inclusion and surface roughness, estimate the critical threshold value as curve I or II.

$A$ — area;

*Subscript: R — Ra; in — inclusion; c — critical.*
The equation of surface fatigue life of curve I is:

\[
N_f = \frac{2}{\pi C (\Delta \sigma)^2} \left\{ \frac{(\Delta K)_c}{2.95 - 2} \left[ \frac{1}{(\Delta K)_0^{2.95-2}} - \frac{1}{(\Delta K)_c^{2.95-2}} \right] - \frac{1}{2.95 - 3} \left[ \frac{1}{(\Delta K)_0^{2.95-3}} - \frac{1}{(\Delta K)_c^{2.95-3}} \right] \right\}
\]

The equation of inner fatigue life of curve II is:

\[
N_f = \frac{9 \times 6.3^2 G}{2E(\Delta \sigma - \Delta \sigma_D^R)^2 a_0} + \frac{a_0^{(1-2.95/2)}}{3.14 \times 10^{-14} \times \Delta \sigma^{2.95} \beta_1^{2.95} \pi^{2.95/2} \left( \frac{2.95}{2} - 1 \right)}
\]
(5) Research on Cold Welding Technology on Engine Cylinder and Cylinder Head  
The macro and micro defects, microstructure and mechanical properties of cold welding material were studied. The related optimization parameters of cold welding technology was determined, and machinability of cold welding area was studied.

- Milling is an effective method to repair the cold welding processed surface.
- From the perspective to control roughness of surface, should choose higher milling speed and smaller feed engagement should be chosen.
(6) Analysis of The Organization Performance of Laser Cladding Layer and its Machinability

Ni based WC function gradient composite coating, Fe based alloy coating and Ni based alloy coating was prepared on substrate of 1Cr13, FV520B, KMN, HT250 and 45# steel by using laser cladding technology. Microstructure of phase, cladding layer, metallographic structure, micro-hardness, abrasion resistance and residual stress were analyzed and tested. Alloy powder material formula and repair process parameters was obtained which has high wear resistance, corrosion resistance and is suitable for repairing typical impeller material injury.
(7) Ultrasonic cleaning and molten salt cleaning technology

- Ultrasonic frequency, oscillator arrangement and the distribution of sound field.
- Studied the DSC curve of nitro molten salt and the variation of molten salt’s surface tension, viscosity with the proportion of molten salt and temperature.

DSC Curve of Nitro Molten Salt
4. Outlook
① The manufacturing processes of enterprise will be linked up by reverse logistics. And the information management system for the whole life cycle of the products or key parts will be built.

② The efficient and high quality disassembling technology and process will be studied. Automatic disassembling equipment will be developed.

③ Environmental friendly cleaning technology: water jet and abrasive water jet, laser cleaning, ultrasonic cleaning, supercritical CO₂ cleaning, molten salt cleaning and so on.

④ Rapid evaluation system for remanufacturability.

⑤ Service security theory and technological process for remanufactured products.
Thank you all!