

# *The Present Situation of Lightweight Technology and Its Application and Thinking in Agricultural Equipment*

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**Abstract:** The implementation of lightweight technology is of great significance to save energy, reduce pollution and achieve sustainable development. Lightweight technology mainly includes the use of lightweight materials, such as high strength steel, magnesium alloy, aluminum alloy, engineering plastics, composite materials), advanced production technology, such as laser tailor-welded plate technology, hydraulic forming technology, high strength steel red-hot forming technology), structural optimization, such as optimizing structure design, the optimal topology design, shape optimization) in three aspects. This paper summarizes the application of lightweight technology in order to provide reference for the future development of lightweight technology of agricultural machinery in China.

## 1. Introduction

Lightweight technology originated from motor sports and is widely used in the automotive field. This technology is not a simple weight reduction, but the integration and unification of design technology, material technology, process technology and connection technology [1]. As far as automobiles are concerned, the overall quality of automobiles should be reduced as far as possible on the premise of ensuring automobile strength and safety performance, so as to improve the power utilization rate of automobile engines and achieve the effect of energy saving and emission reduction. However, in our big agricultural country, many heavy farm work has been replaced by agricultural machinery, and agricultural machinery production also needs to spend a lot of national resources, so the lightweight of agricultural machinery is also imperative. This paper describes the application of lightweight technology in agricultural machinery with the help of automotive lightweight technology.

## 2. Connotation of Lightweight Technology

The concept of lightweight technology has been put forward in the early 1970 s, after decades of development, lightweight technology has been applied to many areas of [2], so far, mainly from lightweight materials, advanced manufacturing technology and structure optimization of these three

aspects, including light materials are mainly high strength steel, aluminum alloy, magnesium alloy, engineering plastics and composite materials. The advanced manufacturing technology mainly includes laser welding plate technology, hydroforming technology and hot forming technology of high strength steel. Structural optimization mainly includes structural optimization design, topology optimization design and shape optimization. Its structure is shown in Figure.1.

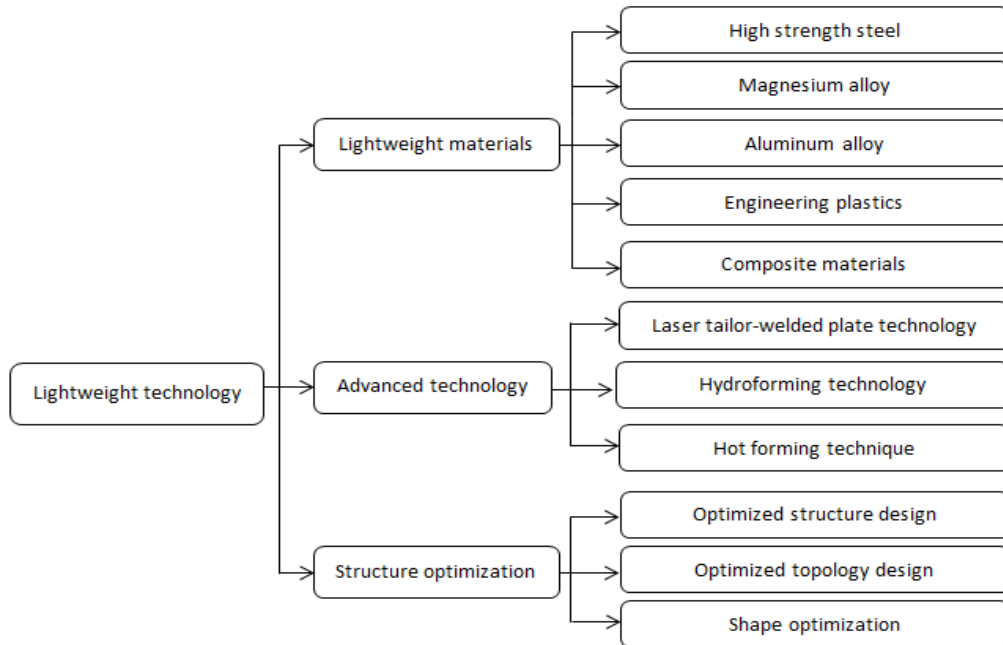


Figure 1: Types of Automotive lightweight technology

### 3. Application of lightweight materials

#### 3.1. High steel strength

High strength steel is characterized by high elastic modulus, good rigidity, good impact resistance and high fatigue strength [3]. Wang Pinjian [4] et al. used hot-formed high-strength steel to replace the original material of the control arm of the front suspension of passenger cars with excessive weight, and finally achieved a 34% reduction in the weight of the control arm. Literature [5] carried out lightweight design for the frame of semi-trailer with single-tire structure, and applied high-strength steel T700 to the original frame to achieve the purpose of reducing the weight of the frame. Guo Jianxin [6] et al. used high strength steel 510L as a substitute for ordinary carbon steel to make tank body in view of the large dead weight of liquid carbon steel tank car widely used at present, which ultimately reduced the weight of tank body by more than 1500kg. Literature [7] carries out lightweight design for automobile body structure, and uses the third generation of high-strength steel to replace the original steel, so that the car body can finally meet the requirements of lightweight design. Xu Xiaopeng [8] et al., aiming at the lightweight design of the chassis of agricultural machinery, adopted the method of replacing raw materials with high-strength steel, which reduced the quality of the chassis of agricultural machinery on the premise that the functions of the chassis of agricultural machinery were not affected and the safety performance was ensured. French Kuhn Company [9] carried out a lightweight design for the main arm of the lawn mower of the pro-longer device. Advanced high-strength steel was adopted to reduce the weight of the main arm of the lawn mower by 23% on the premise of ensuring the safety and reliability of the structure.

### 3.2. Aluminum alloy

Aluminum is only one third as dense as steel and has good mechanical properties, corrosion resistance and thermal conductivity. The alloy also has the characteristics of high strength, easy recovery and good energy absorption [10]. Zhao Chaochen [11] et al. made a lightweight design for an original cast iron steering joint, replacing the raw material with aluminum alloy z1114A-T6, and finally effectively solved the problem of the lightweight of the universal joint. Wang Junfeng [12] et al. took the engine hatchcover of a certain model as the research object and chose aluminum alloy material to replace the original material, thus reducing the quality of the engine hatchcover by 40%. GKN [13] lightweight radiator design, using aluminum alloy as radiator material, not only reduces the weight, but also enhances the strength and fatigue of the radiator. West Coast Agricultural Machinery Company [14] made a lightweight design for the engine and chassis of an amphibious tractor, using aluminum alloy instead of raw materials, and finally reducing the weight of the tractor body to achieve the lightweight effect. However, aluminum alloy is more difficult to process than steel and has poor welding performance, which also limits the processing of aluminum alloy [15]. Li Fuquan [16] et al. adopted laser wire filling welding method for 6005Al aluminum alloy, and adopted solution aging heat treatment method after welding, which can ultimately improve the performance of laser welded joints. Duan Pengfei [17] used liquid nitrogen cooling low temperature cutting technology to effectively reduce the roughness and residual tensile stress of the machined surface, improve the hardness of the machined surface, and refine the surface structure to achieve a good processing effect.

### 3.3. Magnesium alloy

The density of magnesium is only 1.8g/cm<sup>3</sup>, and the performance of magnesium alloy is similar to aluminum alloy, which is the most ideal and lightest metal structure material at present. China is rich in magnesite resources, with the largest reserves in the world, so the prospect is very broad [18]. Liao Jun [19] et al. carried out a lightweight design for the ordinary steel subframe of fuel cell vehicles, using magnesium alloy AZ91D to replace the original steel material, and finally realized the lightweight design of the subframe. In reference [20], for the lightweight design of automobile chassis, the designer used three different materials, iron, aluminum alloy and magnesium alloy, respectively to design the chassis. Through comprehensive analysis and comparison by Ansys Workbench software, it was finally determined that magnesium alloy had the best weight reduction effect. Gao Yunkai [21] et al. used magnesium alloy stamping parts to replace the original steel structure beam to reduce the weight of the roof beam of a domestic car body by about 40%. Lin Dian [22] et al. carried out lightweight design for the rear seat frame of a domestic model, and adopted magnesium alloy instead of the original stamping steel plate welding rear seat frame, reducing the weight of the rear seat frame by 41.3%. Li Jinshan [23] adopted magnesium alloy as the raw material for the development of sprinkler irrigation moving pipe, which not only satisfied the design of sprinkler irrigation moving pipe, but also effectively reduced its weight.

### 3.4. Engineering plastics

Engineering plastics have a small density, about 1/4 of steel; Corrosion resistance with good corrosion resistance; Good friction reduction and self-lubrication; Easy to form, high production efficiency; The cost is low. It is more and more widely used in the automotive field. Worldwide, engineering plastics applied in electronics and electrical appliances account for 26%, vehicles 22%, industrial instruments and equipment 19%, mechanical products 10%, consumer goods and other 28% [24].

Wang Zhenjiang [25] et al., aiming at the design problem of the bumper weight reduction of a domestic SUV, adopted the method of replacing raw materials with plastic, which finally reduced the bumper weight by 11%. Literature [26] carried out a lightweight design for the deflection pulley, the main component of the traditional rope elevator. Glass felt reinforced thermoplastic was used to replace the original gray cast iron material, so as to achieve low quality reduction of the deflection pulley. Wu Meng [27] et al., aiming at the weight reduction problem of steel fins on traditional automobiles, used the structure made of PP-EPDM-TD30 material to replace the original steel structure, so that the automobile fins could meet the weight reduction requirements. Li Fei [28] et al. carried out lightweight design for the tail door of an SUV body, respectively using PPGF30-0455 plastic, PP-TD20 plastic and steel materials to design the inner plate, outer plate and enhanced version of the tail door, and conducted performance analysis through finite element software, finally making the tail door meet the requirements of lightweight design. The bushing of tractor front axle assembly produced by Huaiyin Tractor Factory adopts nylon 66 injection molding bushing, which not only reduces weight, but also meets the use requirements [29].

### 3.5. Composite Materials

Composite material is fiber reinforced plastic, is a kind of reinforced fiber and plastic composite material. The composite material has low density, corrosion resistance, heat insulation and electric insulation, impact resistance and vibration resistance. In terms of weight reduction and strength, it has reached or even exceeded aluminum [18]. Zhan Bowen [30] et al. used composite materials to replace the original steel spiral spring and finally reduced the spring weight by 34.4% on the premise of ensuring safety performance. Zhang Junyuan [31] et al., aiming at the lightweight design problem of rear seat skeleton of passenger cars, adopted the method of replacing metal with long fiber composite material, thus solving the lightweight problem of rear seat skeleton. Reference [32] carried out lightweight design for elevator components, using carbon fiber reinforced plastic (CFRP) as the design material for the elevator wall structure model, making the CFRP elevator model about 50% lighter than the existing elevator. Ye Hui [33] et al. designed the engine hood for weight reduction by using carbon fiber and glass fiber reinforcement materials and epoxy resin matrix materials to carry out structural design of the engine hood and finally concluded that the engine hood with plastic instead of steel is feasible.

## 4. Application of lightweight advanced manufacturing technology

### 4.1. Application of laser tailor-welded plate technology

Laser tailor-welding refers to the integration of several small parts into a large blank by laser welding, and then stamping forming the required integral parts, which is mainly used for the integral forming of parts with different strength, thickness or different surface treatment states [3]. Zhang Ziyu [34] adopted the method of automatic laser welding with special equipment to solve the welding problem of piston rod of automobile shock absorber, thus reducing the weight of piston rod of automobile shock absorber. In reference [35], laser welding with frequency of 2400-3600W is adopted to solve the difficult welding problem of quenched distributed steel in automobile industry, which can not only make the weld morphology obtained by quenched distributed steel basically consistent with the mechanical properties of joints, but also bring into play the advantage of lighter weight quenched distributed steel. Chen Genyu [36] et al., aiming at the laser welding technology that can be used in automobile body-in-white welding production line, combined automation technology, communication technology and laser welding technology, finally reduced the weight of the door. Zhang Qingrong [37] used laser welding technology to weld the special-shaped tube of

tractor front axle. Compared with the seamless special-shaped tube after welding, both impact toughness and mild fatigue of the special-shaped tube have been significantly improved.

## **4.2. Application of hydroforming technology**

Internal high pressure forming, also called hydroforming or hydraulic forming, is a material forming process that uses liquid as forming medium to achieve the purpose of forming hollow parts by controlling internal pressure and material flow [3]. Ni Keren [38] adopted the method of high strength hydroforming to reduce the weight of X80 automobile pipe fittings. Literature [39] analyzes the section of parts of a certain frame and adopts the method of hydroforming to design, which ultimately reduces costs, saves materials and reduces weight of parts. Huang Beixing [40] et al. studied the forming problem of special-shaped tube billet by adopting the method of impact hydraulic expansion, which finally reduced the weight of special-shaped tube billet by 15-30%.

## **4.3. Application of hot forming technology for high strength steel**

Hot forming technology will heat special high-strength steel plate to austenite temperature and then quickly stamping, through the mold pressure preservation and quenching, the material has good formability at high temperature, can effectively reduce springback and ensure the life of the mold, so hot forming technology is an advanced forming technology to achieve the lightweight and safety of mechanical equipment [41]. Yu Kai [42], based on the research on the weight reduction of the crossbeam of passenger car torque beam, used the thermodynamics module of LS-DYNA software to reduce the weight of the crossbeam of passenger car torque beam by combining simulation and experiment. Literature [43] applies hot pressing technology of high-strength steel to automobile body parts, which can not only reduce body weight, but also ensure the safety of passenger compartment. Yu Xiangyun [44] took 30CrMnSi2Nb as the research object based on the research on weight reduction in hot forming of high strength steel for automobile, and adopted the method of combining quenching and partition process with traditional hot stamping process to reduce the quality of high strength steel for automobile. Futian Revo Tractor Manufacturing Company can obtain tractor parts with ultra-high strength through hot stamping forming technology, which can effectively reduce the quality of the body [45].

## **5. Application of structural optimization and lightweight**

### **5.1. Application of optimized structural design**

On the premise of not reducing the overall equipment performance, the optimization of structural design needs to minimize redundant parts in the overall structure, simplify the structural design, ensure the compactness of the structure and improve the effect of lightweight design of mechanical equipment [46]. Zhang Honggang [47] et al. optimized the structure of the wheel designed by the traditional concept, and finally made the wheel not only meet the design requirements, but also reasonably reduce the weight of the wheel. Literature [48] optimizes the design of automobile body structure to achieve weight reduction. Deng Yanshu [49] et al. used structural optimization software to optimize and analyze the model of a certain double-beam gantry crane, and finally effectively reduced the quality reduction of the double-beam gantry crane. Zhou Han [50] et al. carried out structural analysis and optimization design for the engine belt chamber of a diesel engine, and realized the weight reduction of the diesel engine.

## 5.2. Application optimization of topology design

Topology optimization is a problem that seeks the optimal distribution of structure shape and material under the corresponding load in the selected area [51]. The commonly used topology optimization methods include variable density method, evolutionary structure optimization method and level set method, etc.[52]. Wei Chunmei [54] et al. conducted topology optimization for the 3D modeling of flange fork, spline shaft fork and other parts of the transmission shaft of heavy duty vehicles, which ultimately not only reduced the weight of the parts, but also made the parts meet the design requirements. Literature [55] carried out the lightweight design for the hub, and finally realized the lightweight design of the hub by combining reverse modeling technology with topology optimization method. Xue Yajun [56] et al. carried out lightweight design for the suspension bracket of tilting plough, and realized the lightweight of the suspension bracket of tilting plough by combining topology optimization and genetic algorithm. MAO Pengjun [57] et al. carried out topology optimization for the frame of tobacco assisted harvester, established objective function and constraint conditions, and finally effectively reduced the frame quality by 18.77%.

## 5.3. Application of shape optimization design

Shape optimization is the optimization of the geometry of the structure, usually including the optimization of the beam joint position of the truss structure. Optimization of the shape and size of the internal holes of the structure and the boundary size of the continuum [58]. The process of shape optimization is similar to that of size optimization, and an approximate model is usually required [60]. Yang Zhen [61] et al. adopted HyperWorks shape optimization technology to achieve the lightweight design of bridge crane main beam. In order to improve the critical buckling load and fundamental frequency of FG microbeams, the multi-objective shape optimization method was used to optimize the beams, which ultimately not only reached the design requirements, but also reduced its quality and cost reasonably. Suxuan [63] performs initial performance analysis and shape optimization for a door at the conceptual design stage, and finally reduces the quality of the door. Liu Zhao et al analyzed and optimized the shape of a section of tractor cab column, and the column quality was reduced by 6.5% after the section optimization [64].

## 6. Current situation and development trend of lightweight agricultural equipment

### 6.1. Necessity of lightweight of Agricultural equipment in China

China's terrain is complex and diverse, and agricultural equipment is also different, especially in mountainous areas. The realization of lightweight agricultural machinery equipment can not only reduce the weight of equipment, save economic costs, improve its performance, but also better develop agriculture according to local conditions. Therefore, the realization of lightweight agricultural machinery equipment is the general trend.

### 6.2. Status quo and trend of lightweight technology of agricultural equipment abroad

In developed countries such as Europe and the United States, agriculture is very developed, the scale of farms is gradually increasing, and the demand for agricultural machinery is also gradually rising. However, in the face of global warming and energy shortage, lightweight technology becomes particularly important at this time. Figure 2 shows the distance traveled by mobile machinery in Europe, Korea and the United States per liter of oil consumed. The European fuel consumption standard in 2015 was 17 km/L, and now it is set to achieve 21 km/L in 2020, and 23 km/L in 2025,

respectively increasing by 23% and 35% compared with 2015. The U.S. fuel consumption target was 36.2 MPG (15.4 km/L) in 2017, 44.8 MPG (19.0 km/L) in 2020, and 56.2 MPG (23.9 km/L) in 2025, up 24 percent and 55 percent, respectively. Japan's fuel consumption standard was 16.8 km/L in 2015 and is expected to reach 20.3km/L in 2020, an increase of 21% compared with 2015. China's fuel consumption standards are also being strengthened, with a 2020 target of 5 L/100 km, down 28 percent from 6.9 L/100 km in 2015. The variation trend of fuel consumption standards in Europe, South Korea and the United States is shown in Figure 2 [65]. In order to realize the lightweight of agricultural machinery, from the last century, the United States, Germany, Japan and other countries began to use virtual prototyping, virtual manufacturing, virtual factory and other technologies in agricultural manufacturing to innovate the structure and shape design of agricultural machinery, and gradually began to use lightweight materials. Jolun Deer optimized the snaking phenomenon of agricultural equipment at high speed and self-excited vibration under load through virtual prototype technology [66]. Inoue K et al. used computer programs to write finite element program codes for finite element analysis, modal analysis and structural optimization to solve the problem of transmission vibration reduction. In the optimization method, the total vibration energy of the transmission was taken as the objective function to reduce the weight of the equipment, so as to minimize the vibration of the transmission at the excitation frequency [67]. Realizing the lightweight of agricultural machinery can solve a series of problems such as resource shortage and environmental pollution, so it is wise to implement the lightweight of agricultural equipment.

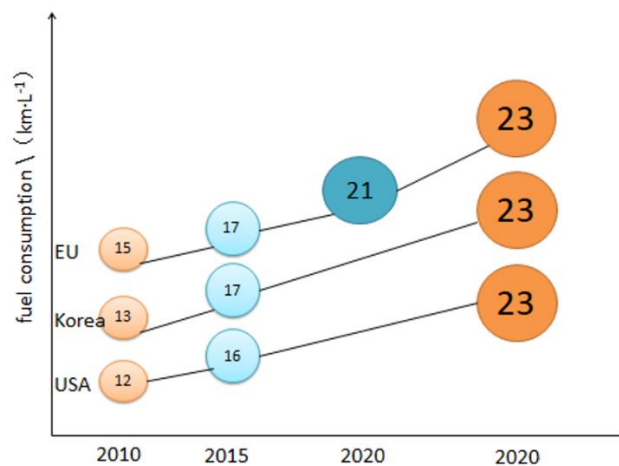


Figure 2: Trend of fuel consumption standards in Europe, South Korea and the United States

### 6.3. Status quo and trend of lightweight technology of domestic agricultural equipment

#### 6.3.1. Current situation of Agricultural machinery in China

According to the data released by the National Bureau of Statistics, in 2018, the total power of agricultural machinery in China was 1.004 billion kilowatts, with the original value of nearly one trillion yuan. The total power was nearly 200 million sets, with 22.4 million tractors and 2.06 million combine harvesters. In 2019, the total power of China's agricultural machinery remained at around 1 billion kw. From 2010 to 2019, the average of the total power of agricultural machinery in China is about 1 billion kW, and the total power of agricultural machinery in China is on the rise.

#### 6.3.2. Ways to achieve lightweight agricultural machinery in China

China is facing energy shortage, environmental pollution and other problems, then lightweight technology is particularly important, lightweight materials are mainly for the development of high

strength steel, magnesium alloy, aluminum alloy, engineering plastics, composite materials. In terms of advanced manufacturing technology, green welding technology will be more widely used in laser welding. Remote welding technology, automation level, development of new component welding materials and forming technology suitable for new lightweight structural parts need to be strengthened. In the aspect of structural optimization, the welding method of ruler material needs to be further developed. The application field of hydroforming process will expand, and the optimization of complex surface and complex dimension, shape and continuum topology will become mature. Figure.3 shows the implementation plan of lightweight for land preparation machinery. Agricultural equipment is also lightweight from three aspects: lightweight materials, structural optimization and advanced manufacturing process.



Figure 3: Lightweight of partial ground preparation machinery

Table 1 shows the unit width weight (unit width (kg/m) of rotary tiller, field returning machine and deep loosening machine of some agricultural machinery enterprises in China. The width of rotary tiller and field returning machine is between 1.5m and 2.5m.

Table 1: Proportion of land preparation agricultural equipment units of well-known agricultural machinery enterprises in China

Unit specific gravity of land preparation machinery (kg/m)	China famous agricultural machinery enterprises										
	A	B	C	D	E	F	G	H	I	J	K
Rotary tiller	200	211	267	240	225	179	175	221	183	200	210
Counters-field panbreaker	308	294	275	290	273	320	173	189	302	320	297
	395	283	192	199	247	213	358	352	344	232	283

It can be seen from the table that there is a certain gap in the unit proportion of land preparation equipment of some domestic agricultural machinery enterprises. The higher unit proportion of rotary cultivator is C enterprise, and the average unit proportion of rotary cultivator is 210kg/m; The unit proportion of returning machine is higher in F and I enterprises, and the average unit proportion of returning machine is 276kg/m. The unit proportion of deep loosening machine is higher in A enterprise, and the average unit proportion of deep loosening machine and tools is 282kg/m.

### 6.3.3. Take the field returning machine of an enterprise as an example to conduct lightweight design analysis

Taking the field returning machine of an enterprise as an example, as shown in Figure. 4, the lightweight technology is applied to compare the weight of the field returning machine before and after using Formula 1 on the premise of ensuring the safety and reliability of the field returning



machine. Table 2 shows the comparison of parameters of a field returning machine before and after using lightweight technology.

$$t_2 = t_1 \times \sqrt{\frac{q_1}{q_2}} \quad (1)$$

Where  $t_1$  is the thickness of the original Q235 steel,  $q_1$  is the yield strength of the original steel,  $q_2$  is the yield strength of SQ500NJ steel, and  $t_2$  is the thickness of the steel to be replaced after calculation.

Table 2: Comparison of parameters before and after the use of lightweight technology for a field returning machine

parameter	Before optimization	The optimized
material	Q235A	SQ500NJ
strength (MPa)	235	500
The price (yuan /kg)	3.5	4.6
Large and small side plate weight (kg)	65	52
Wall weight of tool shaft and tube (kg)	150	124
Total weight of 120 blades (kg)	40.8	32.4
Total weight of the above devices (kg)	255.8	208.4

After calculation, the weight of the above three items is 47.4kg, 5.5% of the whole machine weight. The research shows that if the overall weight of the tractor is reduced by 10%, the fuel efficiency can be increased by 6%-8%. The fuel consumption per mile can be reduced by 0.3-0.6L [68] for every 100kg reduction in the ready weight. According to the conclusion, the fuel efficiency can be increased by 3%~4% and the fuel consumption per mile can be reduced by 0.2~0.3L. The cost was calculated to increase by only 61.7 yuan [68]. Therefore, the application of lightweight technology in agricultural machinery can not only save resources and protect the environment, but also reduce economic costs and improve the performance of the whole machine [68].

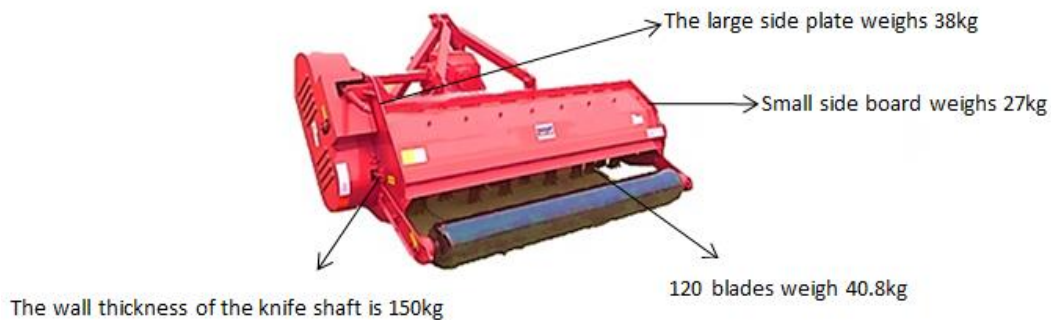


Figure 4: Lightweight design of returning machine

## 7. Conclusions

Lightweight technology originated in the car and spread in the car industry. Lightweight technology also involved in some other areas, such as aerospace and agricultural machinery industry and so on. But at present, the effect of lightweight technology still needs optimization obviously in materials and structures. if we want to get a better lightweight agricultural machinery, we have to get better lightweight materials, better process method, and better structural optimization method. We need to carry on integrated, systematic applications in lightweight agricultural machinery. With the

further development of industrial mode and the progress of computer technology, there is still a great space for the development of lightweight technology in agricultural machinery.

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