The recent developments of shot peening in China

Kewei Xu[1], Chuanhai Jiang[2], Renzhi Wang[3]

1 School of Material science and engineering, Xi'an Jiaotong University, Xi'an, 710049
2 School of Material science and engineering, Shanghai Jiaotong University, Shanghai, 200240
3 Institute of Aeronautical Materials, Beijing, 100095

Abstract: With the development of Chinese industry, shot peening technology is widely used in machinery manufacturing industry in China in recent decade. This paper gives a brief introduction of development of shot peening industry in China, which includes shot peening equipment and peening media manufacturing, process planning about shot peening and application fields of different types of shot peening. In terms of basic research of shot peening, this paper summarizes some notable research results about stress strengthening and microstructure strengthening of shot peening, influence of shot peening on fatigue life of specific material, resistance to some forms of stress corrosion and so on. Furthermore, application of conventional shot peening treatment on advanced materials, new shot peening technique and computer modeling technique about shot peening process also develop very rapidly in China.
Keywords: Shot peening, Development, China

Introduction

Peening machine (PM), peening shot (PS) and peening technologies (PT) are three very important factors of shot peening (SP) treatment technologies for workpieces. The relationship between these three factors has been shown in Fig. 1.

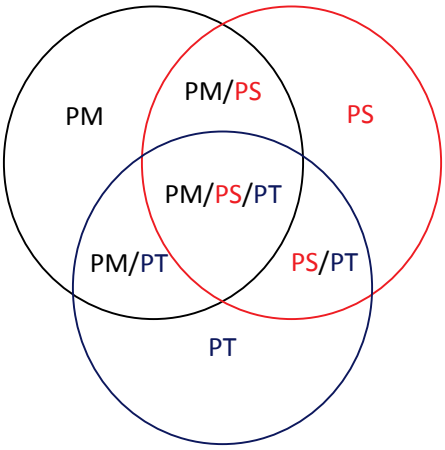

Fig.1. Three factors of SP treatment technologies for workpieces and the relationship with each other.

SP treatment technologies work just like a medicine, which can treat and improve the fatigue fracture resistance (FFR) and stress corrosion cracking resistance (SCCR) of mechanical workpieces. In order to obtain the optimum strengthening effect, the PM and PS must fulfill all the requirements of PT decided by workpieces, such as locations of SP, SP intensities, coverage of surface, roughness of SP and so on.

After SP, the structures of surface layers of workpieces are changed as follows: circulating strain hardening of surface structure and introduced compressive residual stress, which can improve FFR and SCCR of materials/workpiece (M/W) according to structure hardening mechanism and residual stress hardening mechanism respectively, besides, circulating strain relaxation of surface structure and increment of surface roughness can reduce FFR and SCCR of M/W to a certain extent. The variations have been shown in Fig. 2. The SP treatments of M/W should depend on fine PM and PS to obtain composite strengthening effects of the variations mentioned in Fig. 2 to the most degree.

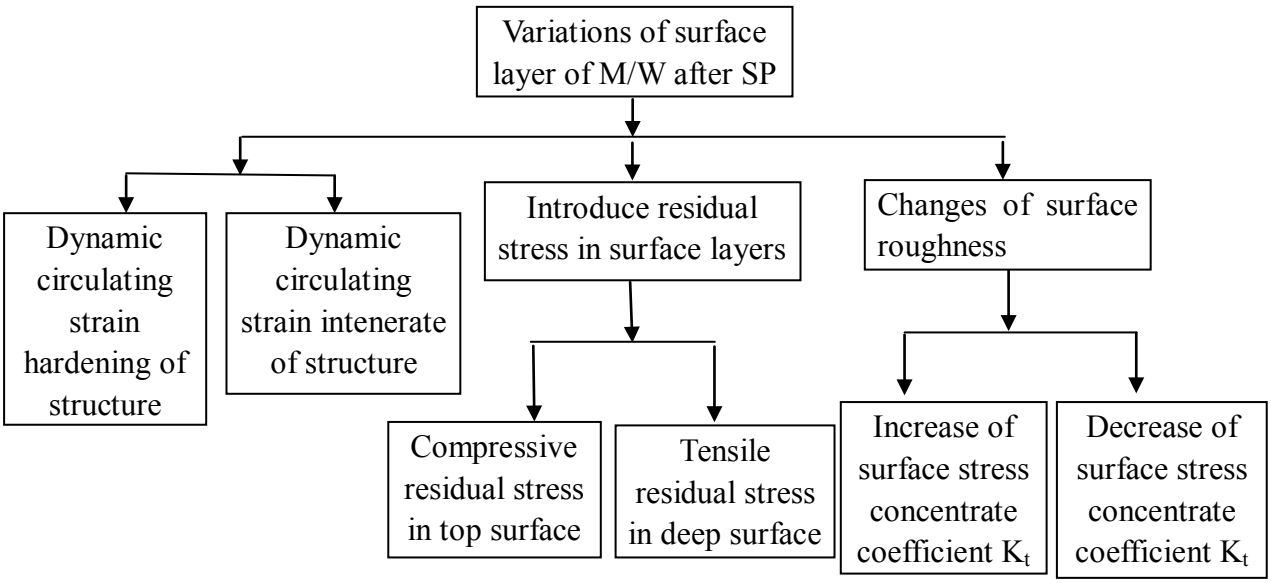

Fig. 2. The changes of workpieces in surface layers after SP

According to the three factors mentioned in Fig.1, combine the development of SP in China and each factor will be presented as follows.

1. The development of PM manufacture

PM is mainly used to modify and improve FFR and SCCR of M/W. And manufacture companies design and fabricate PM according to follow basic principles.

(1) Based on the materials, shape, size, peening location, et al to design the PM.

(2) Based on the risk locations tended to fatigue fracture, and special SP parameters (SP intensities, surface coverage, shot type, size and hardness) to design the PM.

(3) In order to improve the stability and repeat of SP parameters, the shot diameter filter, the cracked shot segregator, the monitor of shot velocity and flux, and other accessories should be fixed in PM.

(4) According to the output, geometric shape, size, and economic benefit of workpieces, consider which type PM will be chose, air blast type PM or mechanical type PM.
Based on above principles, many types of PM have been manufactured in latest 20 years. Some representative types have been displayed as follows.
(1) Special air blast type PM designed for SP on aircraft engines, turbine disc and turbine blade.
(2) Special air blast type PM designed for SP on landing gear workpieces.
(3) Special PM designed for SP on inner-hollow (Φ120mm) long axes (1700mm).
(4) Special mechanical type PM designed for SP on long suckers (8 m) used in oil well.
(5) Special PM designed for SP on suspension spring, valve spring and tunnel workpieces.
(6) Special computerized numerical control (CNC) air blast type PM designed for SP on gas turbine big blade.
(7) Air blast type and mechanical type PM designed for SP on some kinds of gears.
Recently, the combining researches by Shanghai Carthing Machinary Co., Ltd (Shanghai, China) and Shanghai Jiao Tong University (Shanghai, China) make five-shaft dive CNC air blast type PM manufactured, and which makes the high accurate CNC PM homebred firstly. After that, Shanghai Carthing Machinary Co., Ltd has manufactured the robot controlled CNC PM, using the robots on PM successfully. And now, Some CNC PMs made in China have been exported to India, Turkey and other countries. Certainly, it is just the initial development of CNC PM in China, and there is a big gap between developed countries. We will have a long way to go compared with foreign developments.

2. The development of PS manufacture
In 1950's, a few departments of industry (eg. aerial industry) had started using PT. Early, the material of PS was cast steel, then the glass beads were introduced as shot media for aircraft engines workpieces. The peening cast steel shots accorded with SAEJ444a style had been manufactured in 1970's in China. Shandong Kai Tai Industrial Technologies Co., Ltd is the biggest company in China, and the fourth biggest company in the word. In the recent decade, with the fast development of automobile industry, the demands of cutting steel shots become more and more in-country. Some companies like Jiangsu DaQi Group Co., Ltd. as the head can manufacture thousands tons of cutting steel shots each year which are consistent with the standard of SAE J441, AMS2431, MIL-S-13165C, VDFI 8001 and DIN8201. These cutting steel shots can be fulfilled not only the demand of in-country companies, but also exported to the market of Europe.

3. The development of PT manufacture
In 1960's, the influence of SP on the fatigue and fracture properties at elevated temperature of Ni-based high temperature alloys have been investigating in system, and the PT had been used on turbine blade and aircraft engines successfully according to above investigations. The investigations can reduce troubles of turbine blade and prolong the use life in double. The industry standard of "The Illustration of Shot Peening Technologies of Aircraft Workpieces" (HB/Z26-92) designed by aircraft manufacture is the first aeronautical and spaceflight industry standard of P. R. China. In recent 40 years, the experimental study of applied fundamental theory of PT has been shown in follow three facets.

3.1 The experimental study of fatigue and fracture of metal engineering materials

(1) According to the investigation on fatigue crack initiation of engineering materials, micro process theory of fatigue crack initiation has been proposed [1].

(2) According to the investigation on fatigue experiment and observed results, there are two kinds of fatigue limit exist on M/W within fatigue fracture life (N_f = 10^6~10^7cycles), one is fatigue cracks initializing on the top surface of M/W called surface fatigue limit (σ_{ws}) and another is fatigue cracks initializing on the sub-surface of M/W called internal fatigue limit (σ_{wi}) [1].

(3) Based on the dislocation theory, the relationship between σ_{ws} and σ_{wi} can be obtained in the same kind engineering material after heat treatment [1].

$$\frac{\sigma_{wi}}{\sigma_{ws}} = 1.35 \sim 1.40 \qquad (1)$$

Eq.(1) illustrates that if high compressive residual stresses are introduced in the top surface, the fatigue headstream can be suppressed in sub-surface, and the fatigue limit of high fatigue life (N_f = 10^6~10^7cycles) can be improved 35%~40%.

3.2 The calculation of optimized compressive residual stress field in M/W surface introduced by SP [2]

Based on “micro process theory of fatigue crack initiation” and “internal fatigue limit theory”, in order to improve the fatigue limit of high fatigue life (N_f = 10^6~10^7cycles) from σ_{ws} (Surface fatigue limit) to σ_{wi} (Internal fatigue limit), two criterions about obtaining optimized compressive residual stress field have been proposed.

Criterion A: The relationship between σ_{wi} and introduced compressive residual stresses of surface $|\sigma_{rs}|$ has been shown in formula (2).

$$\sigma_{wi} - |\sigma_{rs}| < \sigma_{ws} \qquad (2)$$

It is can be found that with the increase of exterior alternating stresses, the value of σ_{wi} - $|\sigma_{rs}|$ must be less than σ_{ws}, which can avoid surface fatigue fracture at low σ_{ws}.

Criterion B: At the depth of fatigue headstream germinate Z_s (≈Z_t), the sum of the max tensile residual stress ($\sigma_{t,\max}$) introduced by compressive residual stresses and the max tensile stress ($\sigma_{t,\mathrm{ap}}$) caused by the exterior alternating stresses meets formula (3), namely

$$\sigma_{t,\max} + \sigma_{t,\mathrm{ap}} = \sigma_t . \quad (3)$$

$1 > \sigma_t / \sigma_{wi} > 0.96$

From formula (3), it reveals that only σ_t increases and reaches the value of σ_{wi} at Z_s, the fatigue headstream is able to germinate and cause fatigue fracture under higher stresses (σ_{wi}).

Based on above discussion about two criterions, it can be found that only fulfill above two criterions, the introduced residual stress field by SP will be optimized stress field and the effect of peening will reaches the best. This effect of residual stress strengthening is named indirect strengthening mechanism of residual stress.

3.3 Establish the composite strengthening theories of SP

(1) Residual stress indirect strengthening mechanism has been discussed in 3. 2.

(2) Residual stress direct strengthening mechanism

As the fatigue limit of middle fatigue life (N_f = 10^5~10^6 cycles), the PT and introduced compressive residual stresses should fulfil the requirements as follows.

(a) Avoid the increase of stress concentration factor K_t resulted from the increase of surface roughness R_a.

(b) Improve the residual stress of surface σ_{rs} of M/W by choosing an appropriate PT, such as Multi-SP, prestressing SP, warm SP et al.

(c) Improve the residual stress of surface in order to improve fatigue crack germination life (N_i) and reduce the expanding velocity (da/dN) of fatigue crack in residual stress field.

(3) Microstructural strengthening mechanism

There are three kinds of fracture models (FM) of M/W when enduring alternating twist loading, normal tensile fracture model (NTFM), longitudinal shear fracture model (LSFM), and transverse shear fracture model (TSFM). The fatigue fracture life (N_f) is controlled by FM. The experiments of twist fatigue [3] reveal that with the increase of tensile yield strength ($\sigma_{0.2}$) and twist yield strength ($\tau_{0.3}$), the sequence of the length of N_f with different FM is shown as NTFM< LSFM< TSFM. When short N_f of LSFM or TSFM occurs on M/W, the FM can't be changed and N_f can't be improved even though higher compressive residual stresses are introduced according to SP [4]. However, after SP, cycle strain hardening of the structure of surface layer occurs in the process of impact cycle plastic deformation, which can improve $\sigma_{0.2}$ and $\tau_{0.3}$ at surface layer and reverse the FM as NTFM> LSFM> TSFM. Consequently, the variation of structure results in the change of FM and the improvement of N_f, which is the microstructural strengthening mechanism.

In summary, the experimental investigations on PT and the field of applied foundation in China can be concluded in Fig. 3. The aim of SP is that on the base of considering the composite properties of M/W to treat each workpiece. Of course, no metter in the degree of

depth and in the scope, it is not as good as the developed countries on the application of shot peening technologies in the field of manufactures in China. We will work hard to develop the practical application of PT in the different fields of manufactures in China.

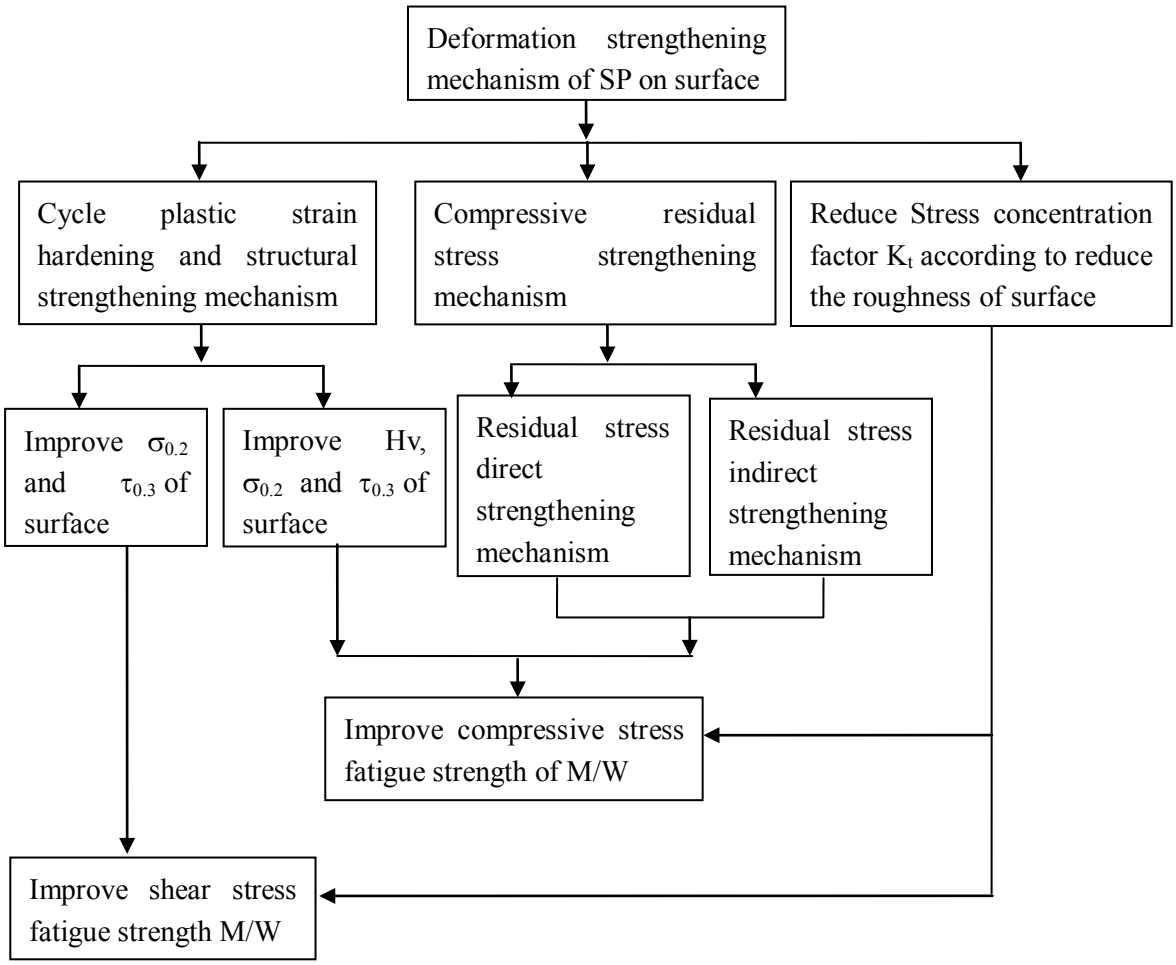

Fig. 3 Composite strengthen mechanism of SP

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