Vol. 10 № 2 Trans. Nonferrous Met. Soc. China Apr. 2000

Article ID: 1003- 6326(2000)02- 0139- 05

Microstructures and mechanical properties of 2014 aluminium alloy forgings made by a new process ①

ZHANG Xin-ming(张新明)[1], SONG Min(宋 旼)[1],
ZHOU Zhuo-ping(周卓平)[1], ZENG Su-min(曾苏民)[2]
1. Department of Materials Science and Engineering, Central South University of Technology, Changsha 410083, P. R. China;
2. Southwestern Aluminium Fabrication Plant, Chongqing 631326, P. R. China

Abstract: The triangular 2014 aluminium alloy forgings were made by a new process and the traditional process. The results showed that the mechanical properties of the forgings made by the new process are far higher than that in the standard of GB223-84, and also higher than that in the standard of EL/53MI-94; moreover, the mechanical properties are almost the same in each direction, and anisotropies are very small. The grains and 2nd phases were analyzed by using TEM and SEM, the results indicate that very fine grains (3~ 6 μm) appear in an approximately isometric way, and a large number of 2nd submicrophases(0.05~ 0.15 μm) disappear in no apparently preferred orientation distribution because the new process involves multidirectional heavy plastic deformation (λ= 12), solution(500 ℃/400 min) and ageing(165 ℃/10 h) heat treatments for a long time at high temperatures. These refined grains, 2nd submicrophases and their almost homogeneous distribution can make it possible for the forgings to display high mechanical properties.

Key words: 2014 aluminium alloy forging; mechanical properties; microstructures **Document code:** A

1 INTRODUCTION

Stricter and stricter requirements on aluminium alloy forgings are always being put forward because of the development of modern aerospace technique, not only for the high strength, low density, but also for the high ductility. The 2014 alloy is a sort of high strength aluminium alloy, extensively used in spaceflight industry[1, 2]. But the mechanical properties of the triangular forgings of 2014 aluminium alloy made by the traditional process can't meet the standard of EL/53MI-94. By the experiments a new process was suggested, the mechanical properties of the forgings produced by which were even higher than that in the standard of EL/53MI-94, and far higher than the standard of GB223-84, thus came up to the requirements of the satellite's launching. The mechanical properties in different directions of the forgings made by two processes are shown in Table 1.

It is obvious that the Standard of EL/53/MI-94 is very high. Though the properties of the forgings made by the traditional process had almost met the Standard of GB223-84, they were not able to be used for the satellite's launching. However, the properties of the forgings made by the new process were higher than that in the Standard of EL/53MI-94, and simultaneously, the anisotropies were very small.

It is a very popular hot topic for researchers in materials science and engineering how to strikingly improve the mechanical properties of traditional metallic materials. Some articles[3~ 10] have indicated that different processing methods and heat-treatment systems will have great influences on the mechanical properties of 2014 aluminium alloy. The with super-strength 650~ 700 MPa can be expected by refining grains and homogenizing structures. If the grains refined are ten times as small as the original, the strengthening increment of the yield strength can be 10 times as high as that of the original metal[11]. In this topic a new process was introduced involving multidirectional heavy deformation, solution and ageing heat treatments for a long time at high temperatures, in order to greatly improve the mechanical properties of the forgings of 2014 aluminium alloy. The forgings were also made by the traditional process as compared with those made by the new one. The grains and 2nd precipitated phases in the forgings made by two processes were analyzed by TEM and SEM, which showed structurally the reason why the mechanical properties of the triangular forgings were greatly improved.

2 EXPERIMENTIAL

Equilateral triangular forgings were made by the following two processes in the investigation, whose shape and dimension are shown in Fig. 1.

Traditional process: unidirectional deformation (λ= 5) $\rightarrow$ machine-shaping $\rightarrow$ solution heat treatment (500 ℃/105 min) $\rightarrow$ quenching (water temperature 50 ℃) $\rightarrow$ cold deformation 4% $\rightarrow$ ageing (150 ℃/4 h)

New process: multidirectional deformation (λ=

① **Foundation item:** Project 1999064908 supported by the National Priority Development Project for Al Fundamental Research
Received date: Jul. 10, 1999; **accepted date:** Oct. 11, 1999

Table 1 Mechanical properties of forgings and two referential standards

Processes and standards	Longitudinal			Transverse			Normal		
	σ_b /MPa	$\sigma_{0.2}$ /MPa	δ /%	σ_b /MPa	$\sigma_{0.2}$ /MPa	δ /%	σ_b /MPa	$\sigma_{0.2}$ /MPa	δ /%
Traditional process	403	348	6.5	362	308	2.6	321	276	1.2
New process	466	454	10.5	457	444	6.3	449	433	4.2
Standard of GB223-84	382		6	353		4	333		2
Standard of EL/53MI-94	435	380	7	435	380	2	420	370	1

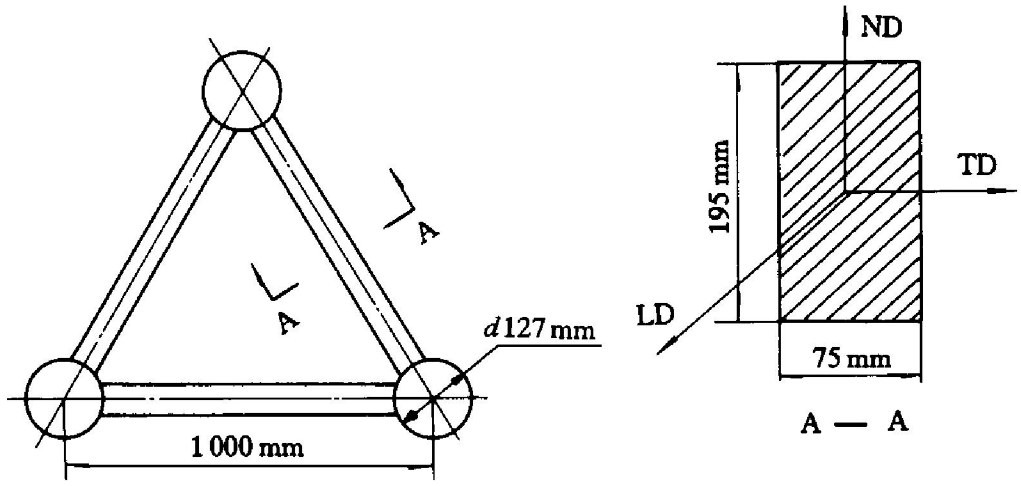

Fig. 1 Shape and dimension of the forgings

12) → finishing → solution heat treatment (500 ℃/400 min) → quenching (water temperature 80 ℃) → cold deformation 4% → ageing(165 ℃/10 h).

The mechanical properties in longitudinal, transverse and normal (LD, TD and ND) directions of the triangular forgings were determined by a tensile test machine (Instron 8032) and the structure were analyzed by SEM (KYKY AMARY 1000B) and TEM (Hitachi H-800) as well.

3 RESULTS AND DISCUSSION

3.1 Microstructures of forgings made by traditional process

The microstructures of the forgings made by the traditional process are shown in Fig. 2 and Fig. 3. It can be seen that there are two kinds of phases, $CuAl_2$ and $(CuFeMg)Al_5$, with bright and dark blocks respectively (Fig. 2(b)), which stretched streakily along the longitudinal direction (Fig. 2(a, b)). But their dispersions in the transverse and normal directions are almost the same (Fig. 2(c, d)). The grains in the forgings remain also longer along longitudinal direction (Fig. 3(a)), and the grain sizes (about 5~10 μm) are unevenly distributed. But along transverse and normal directions the grains become nearly equiaxed (Fig. 3(c)). The dispersed 2-phases (about 0.1 ~ 0.3 μm) (Fig. 3(b, d)) are $CuAl_2$. In some zones, the 2-phases start to become bigger (Fig. 3(b, d)).

According to the experiment, the deformation of the forgings by the traditional process was very heavy in one direction and their total deformation was low. Because of the shorter solution time the recrystallization of the forgings was not completed, the density of the dislocations in the forgings is far higher along LD, thus the precipitation time of the 2-phases becomes shorter and they show an apparently preferred distribution[12, 13]. However because of the shorter ageing time, the precipitation in TD and ND is incompleted, and the fraction of the strengthening phases is less than that in LD. Due to the inhomogeneities of the deformation in some fields of the forgings, some of the precipitated phases begin to become bigger. These inhomogeneities of the grains and precipitations (Fig. 2) will naturally lead to not only the lower strength and ductility, but also more serious anisotropies.

3.2 Microstructures of forgings made by new process

The microstructures of the forgings made by the new process are shown in Fig. 4 and Fig. 5. It can be seen that there are also two kinds of precipitations in the forgings, but the 2nd phases and grains are distributed non-directionally. The grains (about 3~6 μm) (Fig. 5(a)) are nearly equiaxial and the 2nd phases (about 0.05~0.15 μm) are with a great quantity distributed at random (Fig. 5(a, b)). After ageing of 165 ℃/10 h, a needle-like phase S' (Al_2CuMg) is able to be found, identified by spot diffraction (Fig. 5(c)), and it can strengthen the forgings as well. However, it has not been found in the forgings made by the traditional process.

Because of the multidirectional heavy plastic deformation, the distortion of the crystal lattice is serious, the density of dislocations is high, and the

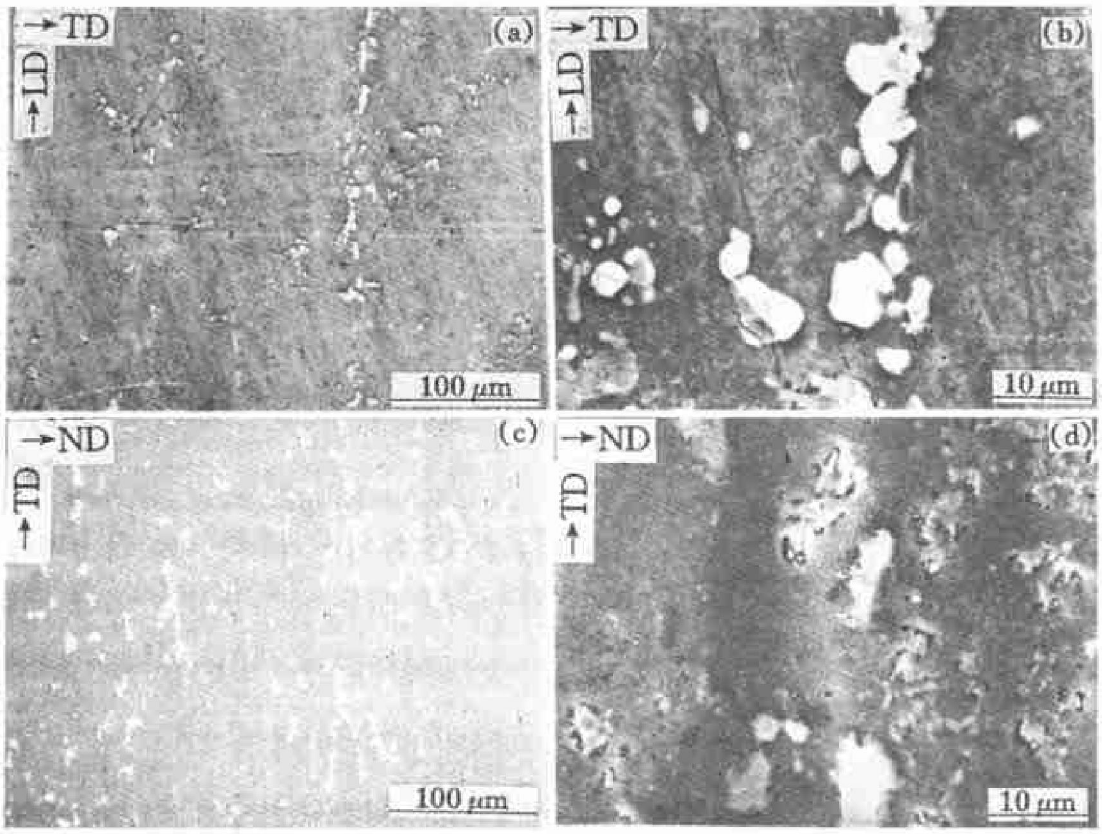

Fig. 2 SEM photos of forgings made by traditional process
(a, b) —Along LD (face L × T); (c, d) —Along TD (face T × N)

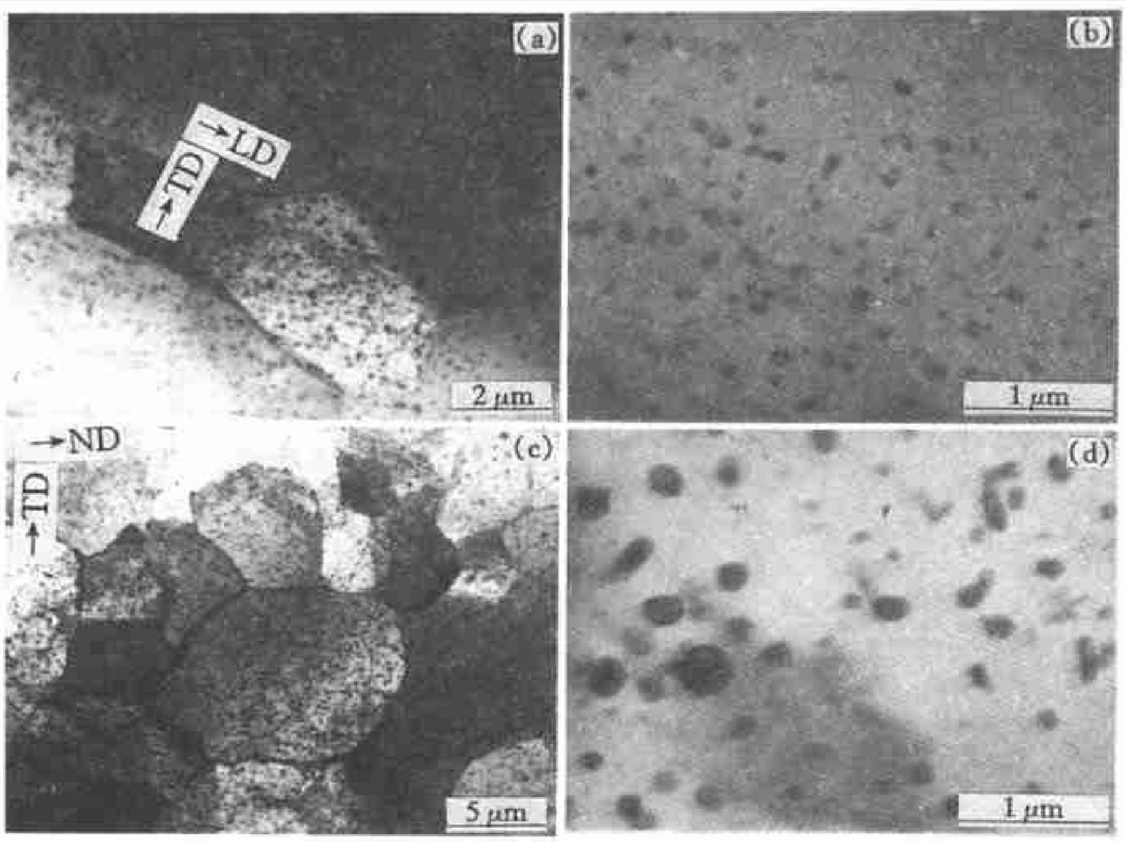

Fig. 3 TEM photos of the forgings made by traditional process
(a, b) —Along LD (face L × T); (c, d) —Along TD (face T × N)

deformation in the forgings will gradually tend to be homogeneous, which will lay the necessary structural foundation for the fine grains and homogeneous precipitations. For the long time (400 min) solution at high temperature (500 ℃), the recrystallization of the forgings has fully been completed and the grains have become very fine. The precipitations in the forgings are able to easily come out in the matrix with the high dislocation density where the nucleation possibilities of the second phases are much greater. The grains and the second phases are only half as large as those in the forgings made by the traditional process. According to the Hall-Petch equation, the strengthening increment of the yield strength is 2 times as much as that of the forgings made by the traditional process. Because the forgings have reached the stage

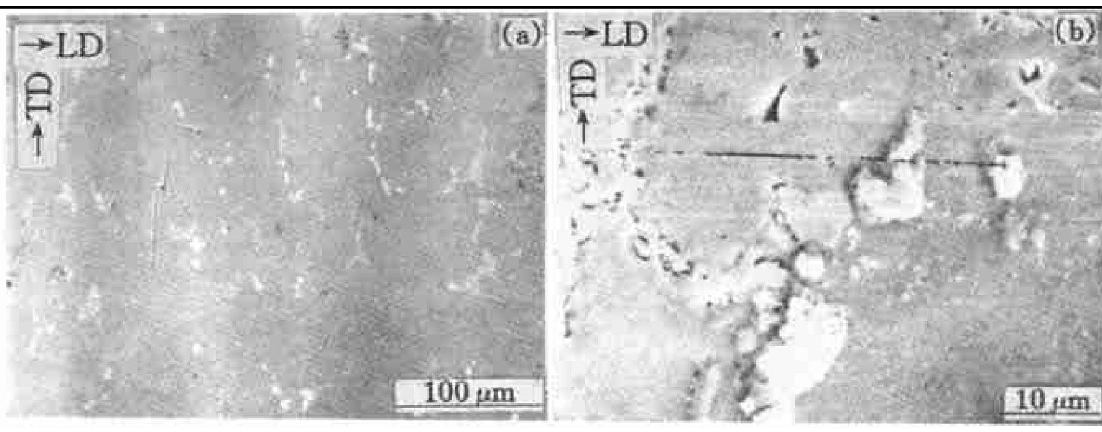

Fig. 4 SEM photos of the forgings made by the new process
(a, b) —Along LD (face L × T)

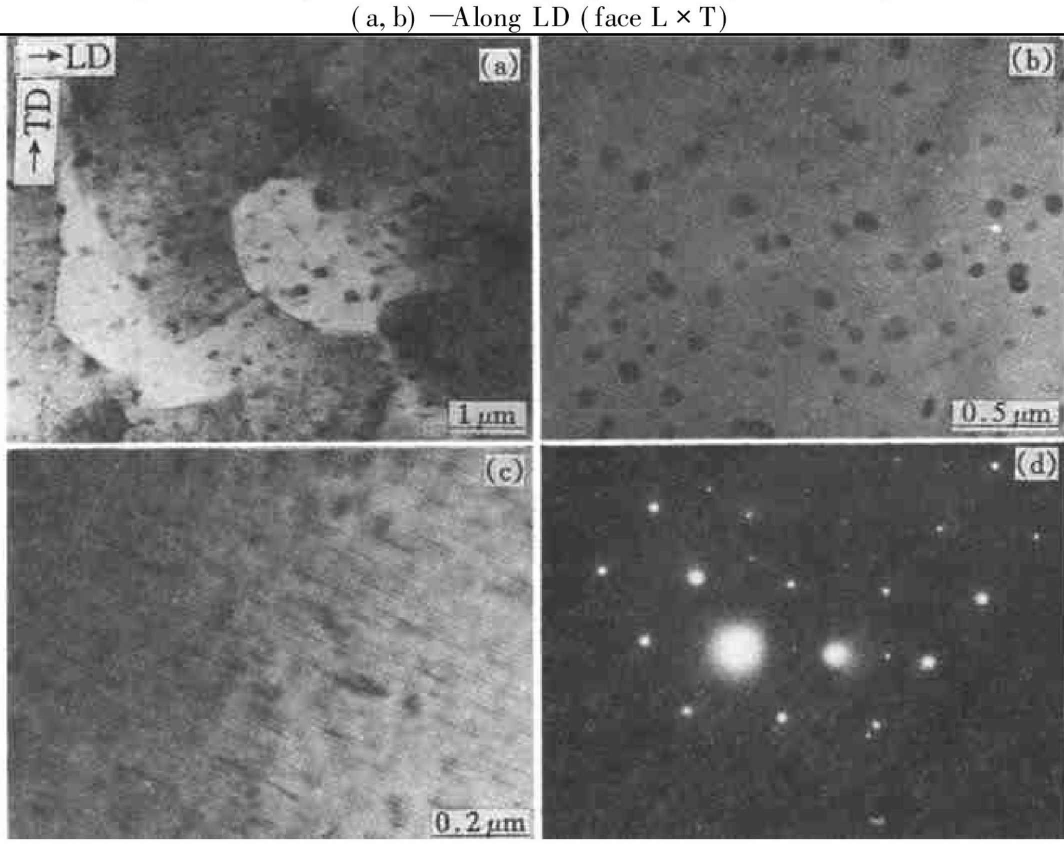

Fig. 5 TEM photos of forgings made by new process
(a, b, c) —Along LD (face L × T); (d) —Diffraction spot of the needle-like phases

of peak value ageing for 10 h at 165 ℃, most of the precipitations have formed an incoherent relationship with matrix, therefore, dislocations would bypass the second phases during deformation and exert a long-range interaction with them, which could improve the strength of the forgings. If the volume fraction of the precipitations is constant, the strengthening increment of the material is directly proportional to the reciprocal of the radius of the incoherent precipitations. Therefore, the increment of the yield strength can be improved one times more than that of the forgings made by the traditional process. Moreover, the refining of the 2-phases and grains is able to make the material deformation homogeneous, thus improve ductility of the forgings greatly.

Due to the very slow precipitation of the phase S' (Al_2CuMg), it is not able to be found in the forgings made by the traditional process, aged for 4 h at 150 ℃. However it appears only in the forgings with high dislocation density made by the new process, aged for 10 h at 165 ℃. This precipitation can also strengthen the forgings further.

4 CONCLUSIONS

1) A new process for 2014 aluminium alloy forgings for high mechanical properties has introduced, and by the multidirectional heavy deformation (λ= 12), solution (500 ℃/400 min) and ageing (165 ℃/10 h) heat treatment for a long time at high temperatures, the mechanical properties of the 2014 triangular forgings are far higher than that in the standard of the GB223-84, and also higher than that of the standard of EL/53MI-94. The anisotropies of the forgings are very small as well.

2) The refined grains (about 3~ 6 μm) in the

forgings made by the new process are dispersed in a nearly isometric way. The precipitations (about 0.05 ~ 0.15 μm) are even dispersed. The grains and second phases are about half as large as those in the forgings made by the traditional process. These refined grains and precipitations have improved the yield strength by about 1.5 times, and the ductility by about 2 times.

3) The fine grains and precipitations in the forgings made by the new process are distributed not in apparently preferred orientations. The anisotropies of the forgings are very small as well.

REFERENCES

[1] Hatch J E. Aluminium Properties and Physical Metallurgy [M]. Chongqing: Publishing House of Science and Technology, 1990.

[2] Knowles D M and King J E. The influence of ageing on fatigue crack growth in an aluminum alloy-SiC whisker composite [J]. Acta Metall, 1991, 39: 793.

[3] FAN Jing-yun, WAN Jing, HE Yun-bin, *et al*. Rapid nondestructive testing of heat-treatment quality of 2014 aluminum alloy [J]. 1999, 9(1): 11~ 16.

[4] ZHANG J S, LIU X J, CUI H, *et al*. Microstructure and properties of spray-deposited 2014+ 15 15% SiC particulate-reinforced metal matrix composite [J]. Metall Trans A, 1997, Vol28A: 1261~ 1269.

[5] Bate P S, Schofield H and Barrett D J. Increasing the drawability of AA2014 Al-Cu by differential heat treatment [J]. Metall Trans A, 1998, Vol29A: 1405 ~ 1413.

[6] Quigley B F, Abbaschian G J, Wunderlin R, *et al*. A method for fabrication of aluminium-alumina composites [J]. Metall Trans A, 1982, Vol13A: 93~ 100.

[7] Christman T and Suresh S. Microstructural development in an aluminum alloy-SiC whisker composite [J]. Acta Metall, 1988, 36: 1691~ 1704.

[8] Samajdar J and Doherty R D. Grain boundary misorientation in DC-cast aluminium alloy [J]. Scr Metall, 1994, 31: 527~ 530.

[9] Dinsdale K, Noble B, Harris S J, *et al*. Development of mechanical properties in Al-Li-Zr-Mg-Cu alloy [J]. Mater Sci Eng, 988, A104: 75~ 84.

[10] Thomas M P and King J E. Comparison of the ageing behavior of PM 2124 Al alloy and Al-SiCp metal-matrix composite [J]. Mater Sci, 1994, 29: 5272.

[11] HE Zhao-Ji. Mechanical Properties of Metals [M]. Beijing: Publishing House of Metallurgy Industry, 1982.

[12] NIE Zuo-ren, ZHANG Xin-ming and YIN Zhi-min. Microstructures and textures in cold-rolled aluminium strip [J]. Transactions of Nonferrous Metals Society of China, 1997, 7(3): 25~ 29.

[13] ZEN Su-min. Structures and properties of advanced materials workshop of materials [R]. Southwestern Aluminium Fabrication Plant. 1999.

(Edited by ZHU Zhong-guo)