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Influences of processing routine on mechanical properties and structures of 7075 aluminum alloy thick-plates①

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Abstract: 7075 aluminum alloy thick-plates were produced by three processing routines: commercial hot-rolling followed by heat treatment of quenching and ageing (HR+ QA), combination of large deformation processing of multi-directional warm forging and subsequent warm rolling followed by heat treatment of quenching and ageing (LD+ QA), and that followed by annealing at moderate temperature (LD+ AN). Tensile strength, yield strength and elongation were measured by tension test, and the metallographic structures were examined by optical microscopy (OM) and transmission electron microscopy (TEM), also the fracture morphologies were observed by scanning electron microscopy (SEM). It is shown that higher tensile strength and yield strength are obtained from (LD+ QA) processing in comparison with those from (HR+ QA) and (LD+ AN) processings. Tensile strength and yield strength obtained from (LD+ QA) processing are 9.9% and 8.6% higher respectively than those from (HR+ QA) processing, and 48.6% and 57.7% higher respectively than those from (LD+ AN) processing; while the elongations of all the samples show no significant difference and keep 10% - 12%. Analyses of OM and TEM reveal that the mechanical behaviors are deeply associated with the formation of refined structures with fine grains and very fine precipitates, leading to fine-grained hardening and excellent age hardening.

Key words: 7075 aluminum alloy; multi-directional large deformation; microstructure; mechanical property
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1 INTRODUCTION

Aluminum alloy 7075, having superior mechanical properties with a high specific strength, is one of the attractive engineering materials for application in aircraft structural parts and other highly stressed structural applications where very high strength and good resistance to corrosion are required[1, 2]. It may perform great differently with different work processing. Investigations on this alloy have always been going on in order to tap its latent power of service[3-7]. Alloying, grain refining and solution-aging are the main methods of strengthening this kind of alloys[8, 9]. While the plastic deformation processes at elevated temperature is a key step for thick-plate fabrication and may have great influence on the structures and properties of this alloy[10, 11]. Products with excellent properties were obtained by some complicate processing routines such as ITMT (Intermediate Thermal-Mechanical Treatment), FTMT (Final Thermal-Mechanical Treatment), TMA (Thermal-Mechanical Ageing)[7, 10-13]. Even so, a lot of research work is worth of carrying out on 7075 alloy and the same kind of alloys.

The present work is to investigate the influences of three processing routines for producing 7075 aluminum alloy thick-plates on the mechanical properties and structures of this alloy. The three processing routines were commercial hot-rolling followed by heat treatment of quenching and ageing (HR+ QA), combination of large deformation processing of multi-directional warm forging and subsequent warm rolling followed by heat treatment of quenching and ageing (LD+ QA), and that followed by annealing at moderate temperature (LD+ AN). Structures were observed and mechanical properties were measured in order to select an optimal process for manufacturing 7075 aluminum alloy thick-plates.

2 EXPERIMENTAL

The testing samples of 7075 aluminum alloy were provided by Northeast Light Alloys Co. Ltd, China. The chemical composition is given in Table 1.

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Table 1 Chemical composition of specimens %

Zn	Mg	Cu	Cr	Mn	Fe	Si	Al
5.31	2.19	1.38	0.29	0.04	0.21	0.14	Bal.

The first processing routine of 7075 aluminum alloy thick-plate (HR + QA) was commercial hot-rolling followed by solid solution treatment at 480 ℃ for 0.5 h in salt bath and quenching in water at room temperature and aging at 110 ℃ for 6h and 170 ℃ for 24 h in resistance furnace. The second routine (LD + QA) was combination of large deformation processing of multi-directional forging at 200 − 350 ℃ with gross deformation coefficient $\lambda \approx 5$ and subsequent warm rolling at 200 − 350 ℃ with 80% thickness reduction followed by the same solution and aging treatment as the first processing routine. And the as-received material was pre-aged at 400 ℃ for 8 h before the large warm deformation. The third one (LD+ AN) was the same deformation process as the second routine but followed by annealing at moderate temperature of 360 − 440 ℃ for 4 − 6 h.

The tensile samples of 2 mm in thickness were cut from the thick-plates and machined so that the loading axis was parallel to the rolling direction. Tension tests were carried out at CSS-44100 testing machine according to GB228-87. The structures of this alloy were observed and analyzed at POLYVER MET Ⅱ metallographic microscope (OM) and H-800 transmission electron microscope (TEM). The fracture surfaces of the tensile samples were analyzed using KYKY-2800 scanning electron microscope (SEM).

3 RESULTS AND DISCUSSION

3.1 Mechanical properties

The results of the tensile test were listed in Table 2. It is obvious that higher tensile strength (σ_b) and yield strength ($\sigma_{0.2}$) were obtained from (LD+ QA) processing in comparison with those from (HR+ QA) and (LD+ AN). Tensile strength and yield strength of sample obtained from (LD+ QA) processing are 9.9% and 8.6% higher respectively than those from (HR+ QA) processing, and 48.6% and 57.7% higher respectively than those from (LD + AN) processing; while the elongations of all the samples show no significant difference and keep 10% − 12%.

Table 2 Tensile properties of 7075 aluminum alloy thick-plates in rolling direction

Processing routine	Mechanical property		
	Tensile strength, σ_b/ MPa	Yield strength, $\sigma_{0.2}$/ MPa	Elongation, δ_5/ %
HR+ QA	451.8	403.2	10.7
LD+ QA	496.4	437.8	10.7
LD+ AN	334.2	277.7	11.7

3.2 Structures analysis

Optical microstructures of the materials obtained from the three processing routines are shown in Fig. 1. It can be observed that the first processing routine (HR+ QA) provided a completely recrystallized microstructure with very large grains in both transverse direction and rolling direction and with coarse second particles, as

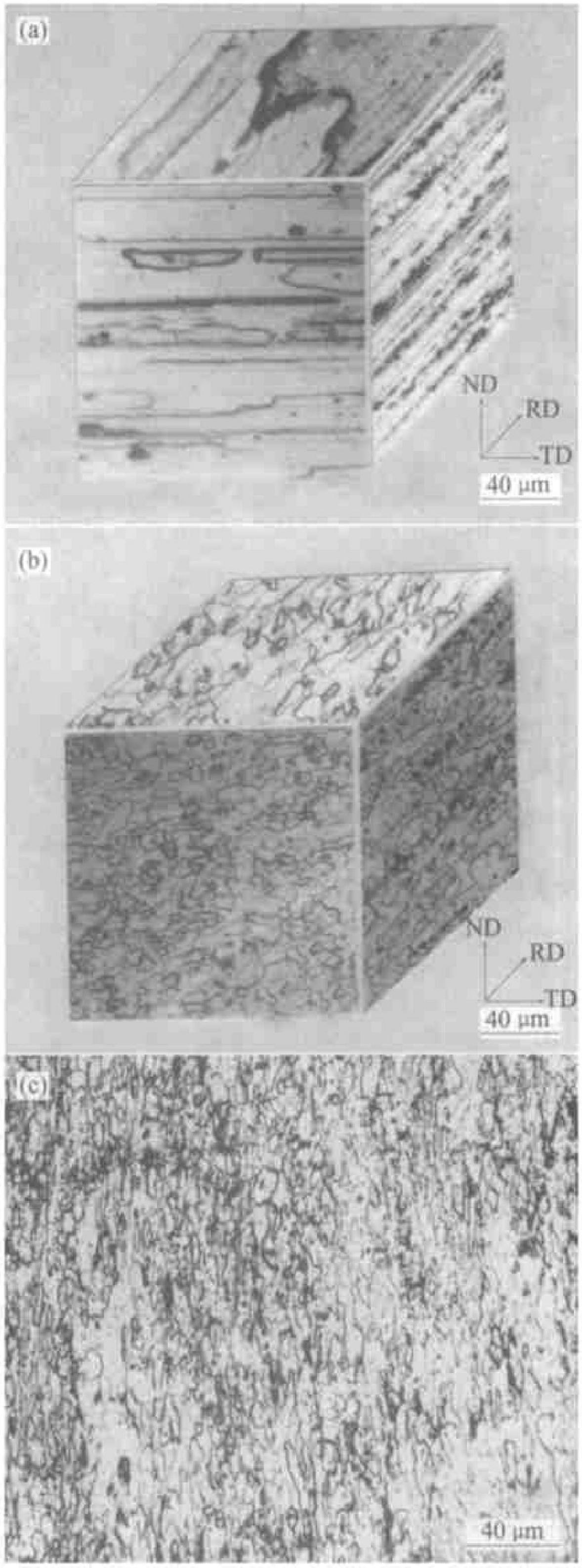

Fig. 1 Optical micrographs of samples obtained from three processing routines
(a) —HR+ QA; (b) —LD+ QA; (c) —LD+ AN

shown in Fig. 1(a). While the second processing routine (LD+ QA) presented a very fine recrystallized microstructure, as shown in Fig. 1(b). The average grain size was around 8 μm in the transverse direction and 12 μm in the longitudinal direction. The second particles were much more fine and distributed more uniform. The third processing routine (LD+ AN) contained a partially recrystallized microstructure with both fine grains and un-recrystallized deformation zones, as shown in Fig. 1(c).

TEM analysis revealed the substructures of these samples, as shown in Fig. 2. Grains were refined by (LD+ QA) process, and the recrystallized structure of the material was stabilized by the movement of grain boundaries which was retarded by second particles with the size of more than 0.1 μm before aging (arrow in Fig. 2(a)). High density of fine precipitates emerged from the matrix after aging, and PFZ (precipitate-free zone) formed at the grain boundaries (as shown in Fig. 2(b)). Some dislocations may remain in the materials after recrystallization and aging, but they were locked by particles and presented excellent stability (as shown in Fig. 2(c)). Dense fine precipitates were also observed in the sample obtained from (HR+ QA) processing, but it was difficult to find a grain boundary in the large grains. A large number of sub-grains and undeveloped recrystallized grains with the average size of 0.5 μm formed in the sample obtained from (LD+ AN) processing (as shown in Fig. 2(d)). The truth that these fine grains and sub-grains are not stable and recrystallization may continue provided that enough energy was given by elevating the temperature or/and deformation.

3.3 Discussion

High mechanical properties of this kind of alloy are often deeply associated with the formation of refined structures with fine grains and very fine precipitates, leading to fine-grained hardening and excellent age hardening[6, 7, 12]. Dynamic recrystallization and severe dynamic recovery may well occur during hot rolling above 450 ℃, and it was disadvantageous to grain refinement. So, as shown in Fig. 1(a), the first processing routine (HR+ QA) provided a very large elongated grain. But the samples from this routine got excellent age hardening by the double-step aging treatment and had mod-

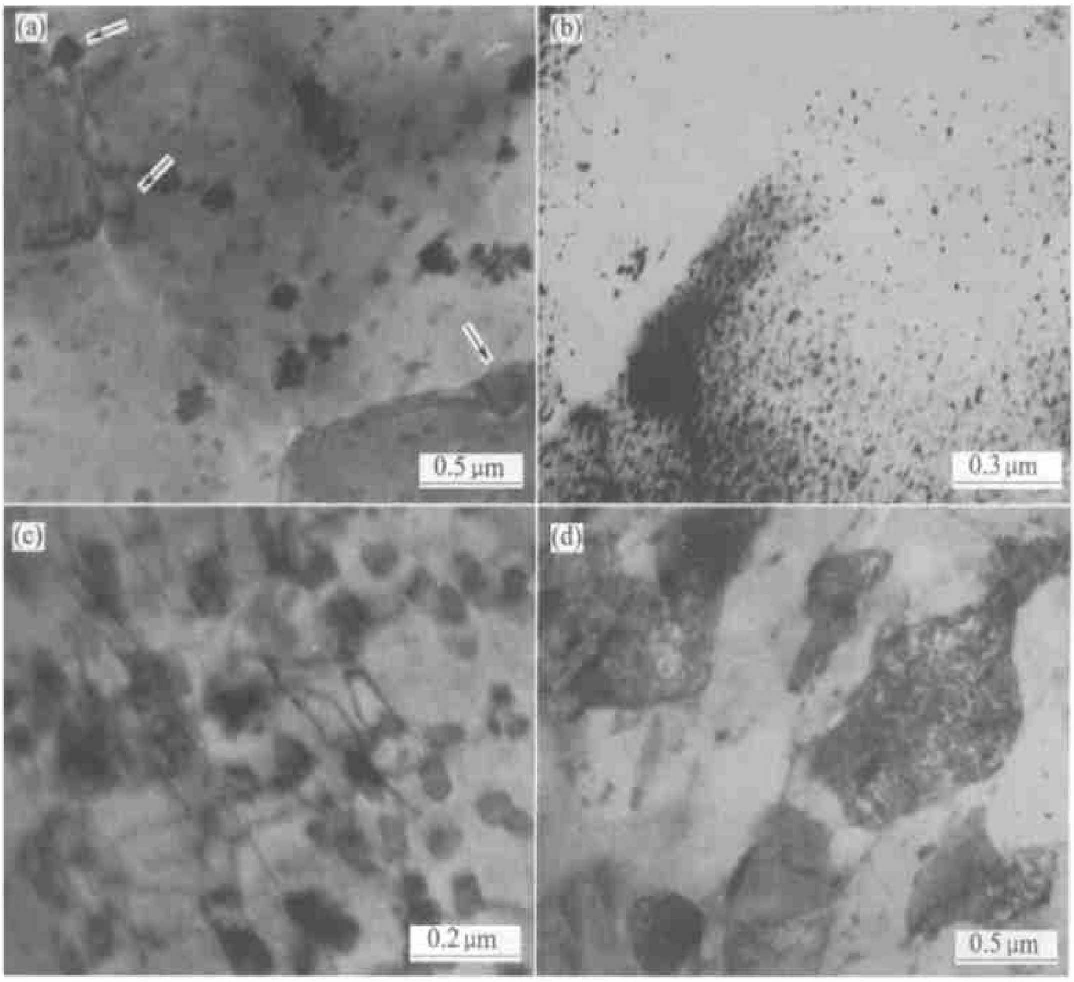

Fig. 2 TEM morphologies of 7075 aluminum alloy
(a) —Recrystallized grains before aging, obtained from (LD+ QA);
(b) —Dense precipitates after aging, from (LD+ QA);
(c) —Dislocations locked by fine particles, from (LD+ QA) or (HR+ QA);
(d) —Sub-grains and undeveloped recrystallized grains, from (LD+ AN)

erate mechanical properties. The second processing routine was in fact a TMT (thermal-mechanical treatment), which, as selected, increased the volume fraction of coarse particles during pre-aging and consequently increased the tendency towards an inhomogeneous strain distribution during the subsequent plastic deforming. So nucleation ratio of recrystallization was enhanced during heat treatment[10-13]. Multi-directional forging and rolling at moderate temperature not only conducted large uniform deformation and heavy strain to the material, but also restrained dynamic recrystallization and recovery, and restored high deformation energy and high density of dislocations, which greatly facilitated the refinement of grains and second particles (as shown in Fig. 1(b)). The dense and fine precipitates after aging strengthened and stabilized the material by retarding the movement of dislocations and grain boundaries. Therefore, it is not difficult to understand that its high tensile strength and yield strength are mainly due to the combination of fine-grained hardening and excellent age hardening. The partially recrystallized structure presented in the (LD+ QA) processing (as shown in Fig. 2(d)) was also strengthened by the fine grains and sub-grains according to Hall-Petch equation[12]. But it gets almost no age hardening because of annealing at lower temperature and receiving no aging treatment and then present very low strengthes.

SEM morphology observations on the fracture regions of the samples submitted to tension tests showed a predominantly inter-granular fracture surface in the recrystallized microstructure, although some trans-granular areas are evident, and (LD+ QA) sample included more of these areas than (HR+ QA) sample (as shown in Fig. 3(a) and (b)). While the fracture of the sample with partially recrystallized microstructure was mainly trans-granular, showing the alternate areas containing dimples in a plane normal to the stress axis and shear areas oriented parallel to the stress axis (as shown in Fig. 3(c)), and presented some higher elongation. The SEM micrographs also indicated that inter-granular fracture was mainly started from the coarse particles and strain concentrations on grain boundaries, and the trans-granular fracture was chiefly nucleated by the strain concentrations of shear bands. The particles, coarse or fine, which strengthened the recrystallized materials, may well be nucleation sites of fractures when the sample is submitted to over strain. The elongation over 10% of the sample from (HR+ QA) processing was principally due to the plastic deformation in the large grains. This result is similar to that of other investigators[6, 7, 14, 15] and indicates that TMT technique including the combination of large deformation

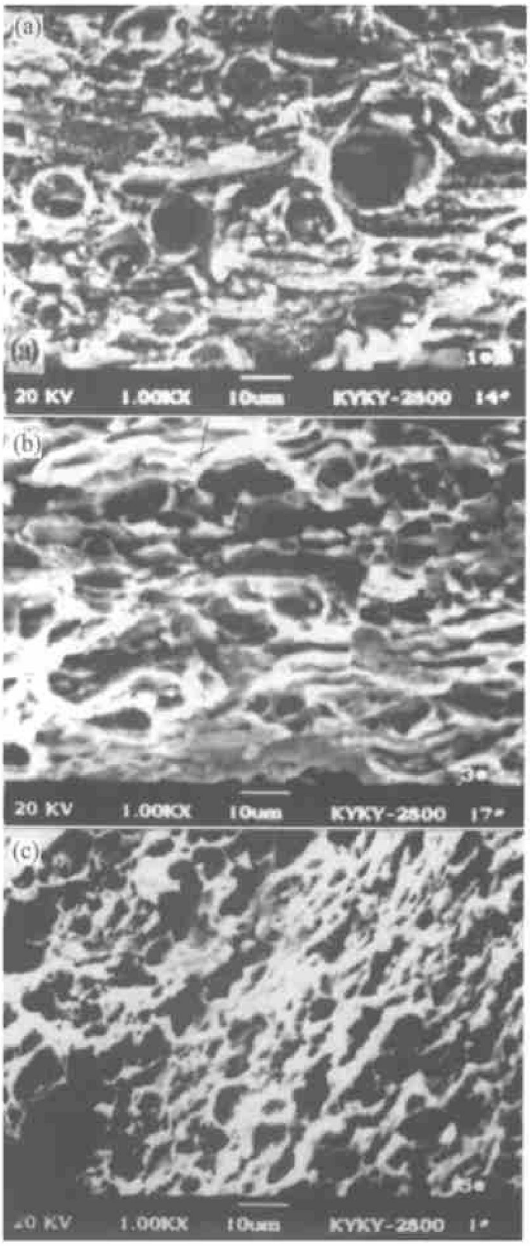

Fig. 3 SEM micrographs of fracture surfaces of samples submitted to tension tests
(a) —HR+ QA; (b) —LD+ QA; (c) —LD+ AN

processing of multi-directional warm forging and subsequent warm rolling followed by heat treatment of quenching and ageing (LD+ QA) is one of the most effective methods to produce fine-grained structure and can enhance strength without a decrease of ductility.

4 CONCLUSIONS

1) The higher tensile strength and yield strength are obtained from (LD+ QA) processing in comparison with those from (HR+ QA) and (LD+ AN) processings. Tensile strength and yield strength obtained from (LD+ QA) processing are 9.9% and 8.6% higher respectively than those from (HR+ QA) processing, and 48.6% and 57.7% higher respectively than those from (LD+ AN) processing. While the e-

longations of all the samples show no significant difference and keep 10%－12%.

2) The main strengthening mechanism of sample from (LD+ QA) processing is the combination of fine-grained hardening and excellent age hardening, while the (HR+ QA) sample is strengthened chiefly by age hardening, and the (LD+ AN) sample get only weak hardening from fine sub-grains.

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