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Recrystallization textures and microstructures of Al-0.3%Cu alloy after deformation to high strains

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Abstract. An Al-0.3%Cu alloy was deformed to high strains by cold rolling. The as-deformed samples were annealed at different temperatures until complete recrystallization. The cold rolling textures were determined by X-ray diffraction while the recrystallization textures and microstructures were characterized by electron backscatter diffraction. It was found that the rolling texture was characterized by a strong Brass component. After complete recrystallization Goss and Cube textures were developed. The effects of deformation strain and annealing temperature on the recrystallization textures are discussed.

1. Introduction

The recrystallization texture of aluminium alloys has been studied for many decades due to its importance for the mechanical properties and formability of Al alloys. It is known that the development of a recrystallization texture is strongly dependent on the deformation texture. As a typical face centred cubic (FCC) alloy with a high stack fault energy, Al alloys reveal a well-known rolling texture called the β-fibre, which runs from Brass {110}<112> through S {123}<634> to Copper {112}<111> texture components during plastic deformation [1] The Brass component is usually weaker than the S and Copper components.

During subsequent annealing, recrystallization textures develop usually having components of Cube {001}<100>, retained rolling texture and/or random orientation [2]. In some cases, P {110}<111> and/or Cube$_{ND}$ {001}<310> components are formed in Al alloys containing particles [3].

However, in our recent experiment a strong Goss {011}<100> texture was found in the centre layer of the Al-0.3%Cu sheets after being cold rolled to 98% and annealing at 300℃ [4]. In this paper, the Al-0.3%Cu alloy was cold rolled to different strains and annealed at different temperatures until complete recrystallization. The textural evolutions during deformation and annealing were investigated.

2. Experimental

The material used in the present investigation was an Al-0.3%Cu alloy, which was casted using 5N Al and an OFHC Cu. The ingot was forged at 200℃ to obtain a plate 50mm thick. The material has a very coarse grain size of about 1.5-2mm. The as-forged plate was then cold rolled to 80%, 90%, 95%

and 98% reductions in thickness. To ensure homogeneous deformation for each rolling pass, the contact length to mean thickness ratio (l/h) was controlled to be ~2.5 [5]. All the cold rolled samples were annealed at 200, 300 and 400 ℃ in a tube furnace for different times until complete recrystallization. The samples were inserted into the furnace when the furnace temperature reached the desired temperature. Then it took about 5 minutes for the temperatures to be stabilized at the setting points.

The textures of the as-forged and cold-rolled samples were measured at the centre layer of the samples by X-ray diffraction on the rolling plane. The samples were 10 mm long along the rolling direction (RD) and 8 mm wide along the transverse direction (TD). (1 1 1), (2 0 0), and (2 2 0) pole figures were measured up to a maximum tilt angle of 70° by the Schulz back-reflection method using Cu-Kα radiation. The orientation distribution functions (ODF) were calculated. Volume fractions of different texture components were calculated from the ODFs. The microstructures and textures of the annealed samples were measured on the longitudinal section, using an Oxford Aztec electron backscatter diffraction (EBSD) detector attached to a TESCAN MIRA3 scanning electron microscope. Texture components were defined as within 15° from their ideal orientations.

3. Results

To ease the description of the results, Figure 1 illustrates the texture components that are relevant for the present study. As an example, figure 2 shows the ODF for the as-forged state. The orientation of the highest intensity does not correspond to a typical texture component although a relatively weak Goss component is seen. The high intensity is caused by the presence of a limited number of grains in the measured area due to the large grain sizes (1.5-2mm). Several similar X-ray measurements showed the occurrence of high intensity at different orientations. These observations indicate that the as-forged sample has a weak texture.

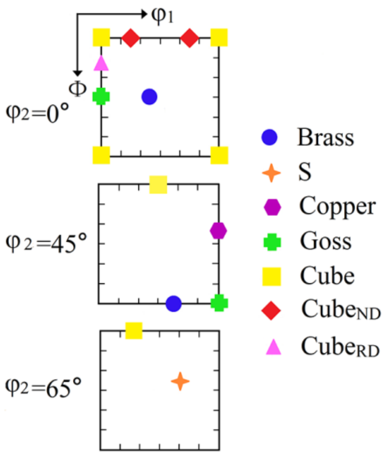

Figure 1. ODFs position of the texture components relevant for the present study.

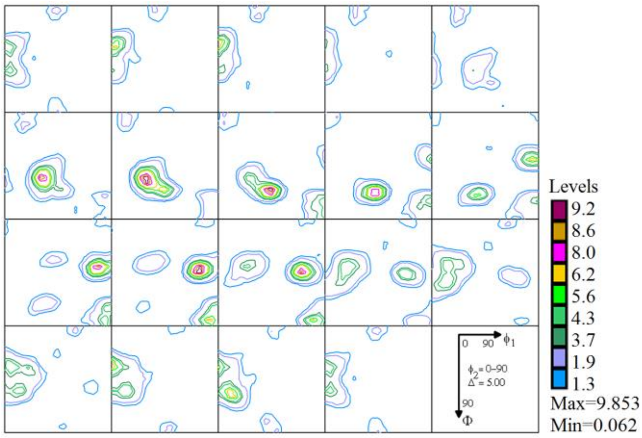

Figure 2. ODFs of the as-forged sample

Figure 3 shows the texture evolution of the Al-0.3%Cu alloy cold rolled to 80%, 90%, 95% and 98% reductions in thickness, respectively. It is seen that a typical rolling texture is developed after cold rolling to 80%. Along the β-fiber of the rolling texture, the Brass component shows a higher intensity than the S and Copper components.. Beside these typical rolling texture components, there exists a weak Goss component at all strains.

Figure 4 shows the evolution of the volume fractions of individual texture components during rolling. It is seen that the volume fraction of Brass component increases while those of S and Copper compnents decrease with increasing rolling reduction over the range of 80 -98%. At all strains, the

Brass component has much larger volume fractions than S and Copper components. Besides, there are about 5-10% Goss grains at all strains.

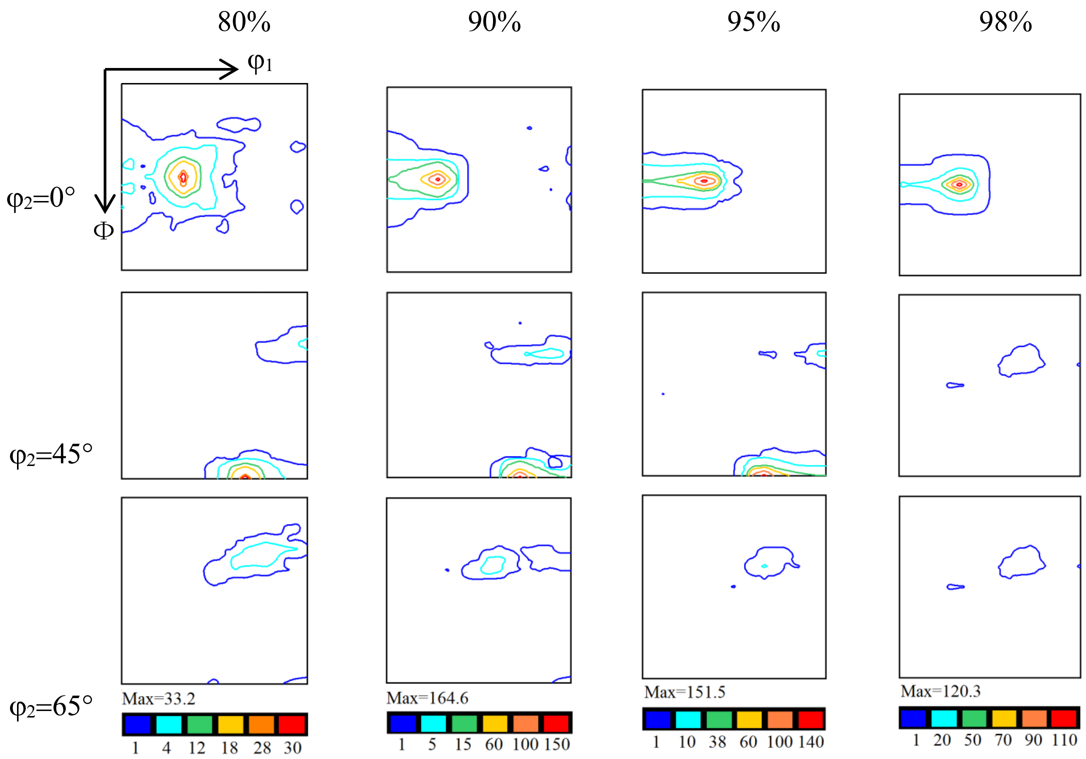

Figure 3. Sections $\phi 2 = 0°$, $45°$, $65°$ in the ODF of the samples cold rolled to thickness reductions of 80, 90, 95 and 98.

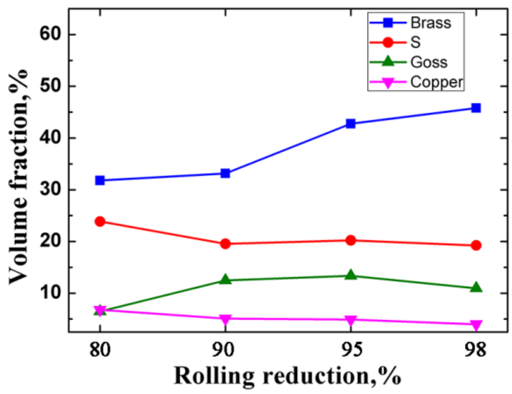

Figure 4. Evolution of the volume fractions of individual texture components during rolling.

The microstructures and textures after complete recrystallization are shown in Figure 5 and Figure 6, respectively. After recrystallization, the textures are mainly $Cube_{RD}$ (Cube rotated about RD), Goss and $Cube_{ND}$ (Cube rotated about ND), all seen in the section of $\phi 2=0°$ of the ODF. Therefore only this section is shown in Figure 6. After completely recrystallized at 200℃, the recrystallized grains are elongated along RD (see Figure 5(a)-(d)). Cube and $Cube_{RD}$ components are developed in the 80% deformed and annealed sample. $Cube_{RD}$ still dominates the recrystallization texture in the 90%

deformed and annealed sample. As the rolling reduction increases, Cube and Cube$_{RD}$ components almost disappear while a Goss component is increasing (see Figure 6(a)-(d)). It indicates that the recrystallization texture transforms from Cube and Cube$_{RD}$ components to a Goss component when annealing at 200 ℃. Figure 5(e)-(h) show equiaxed recrystallized grains after complete recrystallization at 300℃. Cube$_{ND}$, Goss and Cube$_{RD}$ components are observed except for the 98% deformed sample, which only exhibits a strong Goss texture with a weak Cube$_{ND}$ component (Figure 6(e)-(h)). The intensity of the Goss texture increases with increasing rolling reduction. After complete recrystallization at 400℃, very coarse grains are formed in the samples (see Figure 5(i)-(l)). The recrystallization texture is relatively random with weak textures around Cube and Goss in the 80% and 90% deformed samples, while for the samples deformed to reductions of 95% and 98% a strong Cube$_{ND}$ are observed after recrystallization (see Figure 6(i)-(l)).

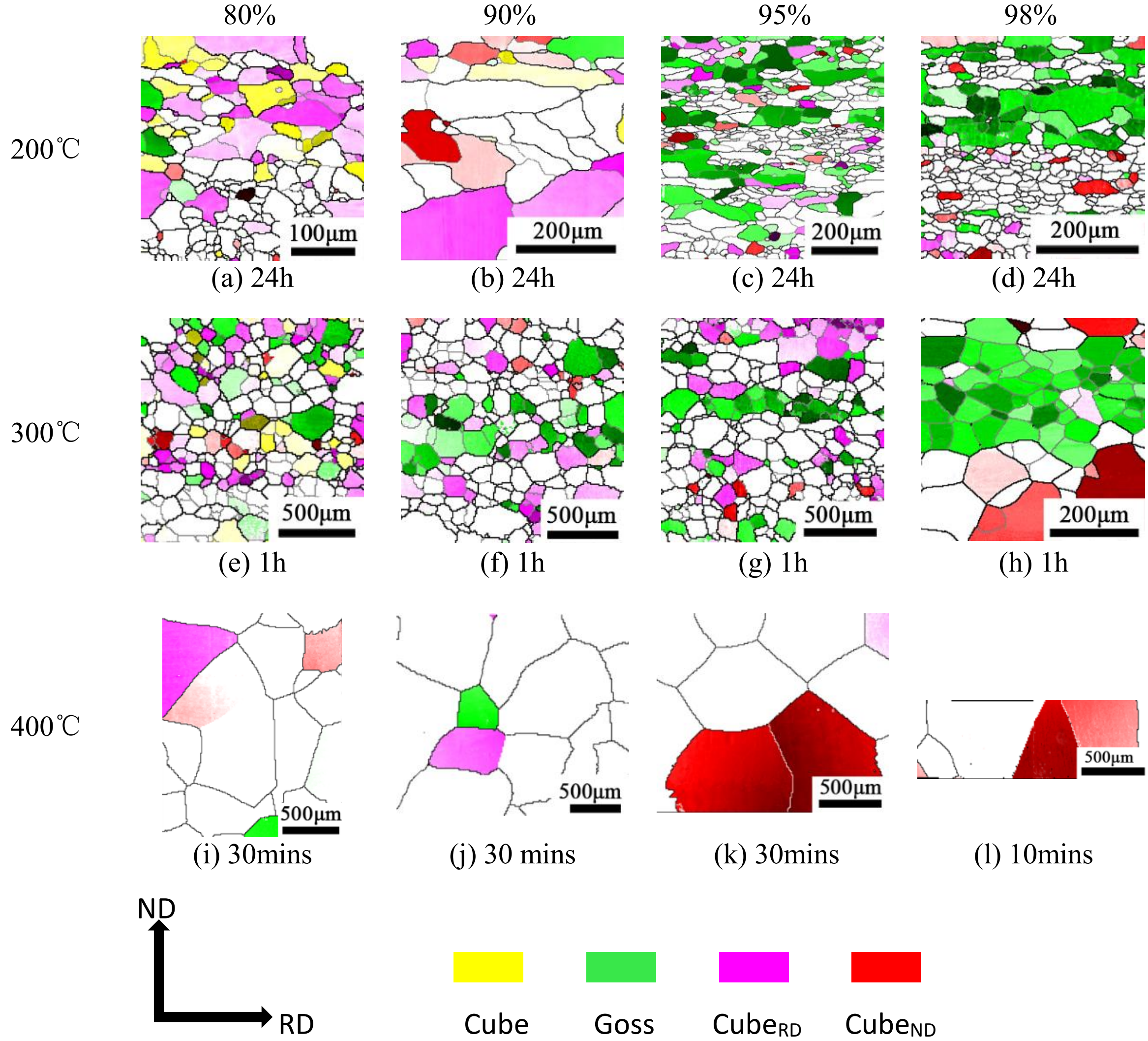

Figure 5. EBSD maps of Al-0.3%Cu after cold rolling to (a), (e), (i) 80%, (b), (f), (j) 90%, (c), (g), (k) 95% and (d), (h), (j) 98% followed by complete recrystallization at (a), (b), (c), (d) 200℃ for 24 hours, (e), (f), (g), (h) 300℃for 1hour and (i), (j), (k)400℃for 30minutes and (l) 400℃ for10minutes, respectively. In the maps, light grey lines and black lines represent grain boundaries ≥2° and ≥15°, respectively.

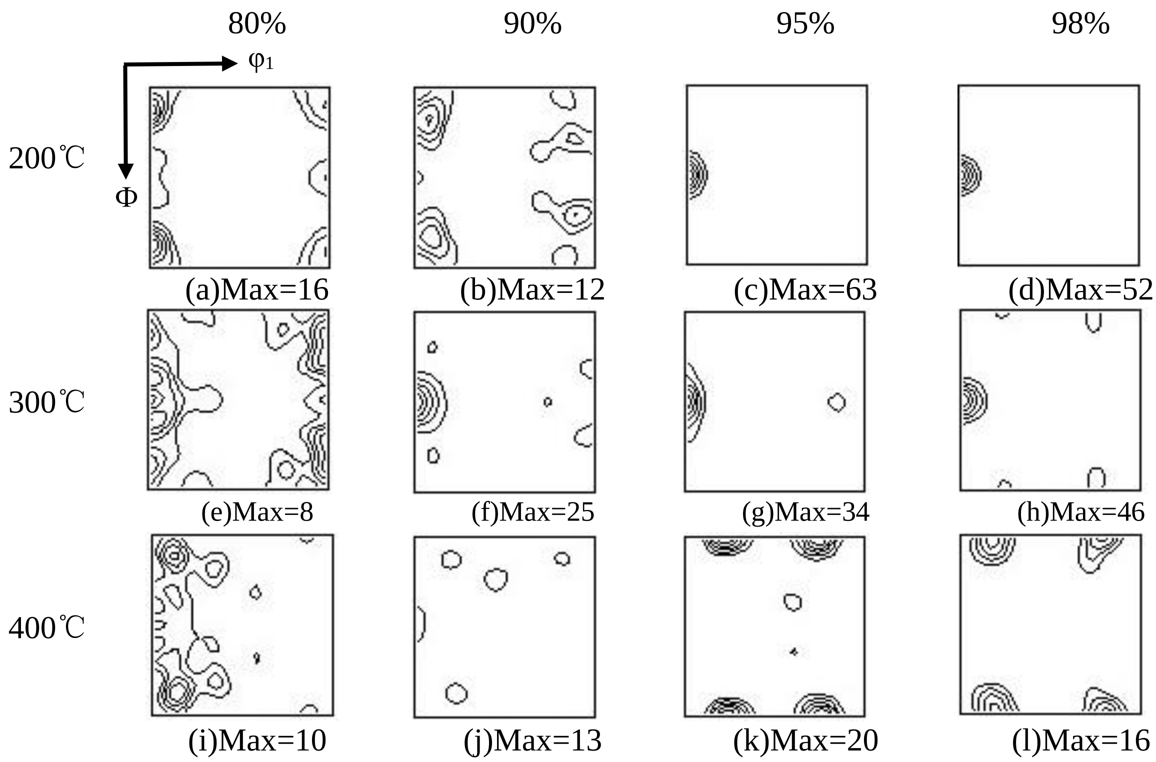

Figure 6. φ2 = 0° sections of ODFs of Al-0.3%Cu cold rolled to (a), (e), (i) 80%, (b), (f), (j) 90%, (c), (g), (k) 95% and (d), (h), (j) 98% followed by complete recrystallization at (a), (b), (c), (d) 200℃, (e), (f), (g), (h) 300℃ and (i), (j), (k), (l) 400℃.

Figure 7 shows the effects of annealing temperature and rolling reduction on the recrystallization texture for the Al-0.3%Cu alloy. It is found that the volume fraction of the Goss component increases with increasing rolling reduction when the samples were annealed at 200℃ and 300℃, whereas the Goss orientation almost vanished after recrystallization at 400℃(Figure 7(a)). $Cube_{ND}$ orientation is obtained only in highly deformed and high temperature annealed samples (Figure 7(b)). $Cube_{RD}$ decreases in volume with increasing rolling reduction and annealing temperature (Figure 7(c)).

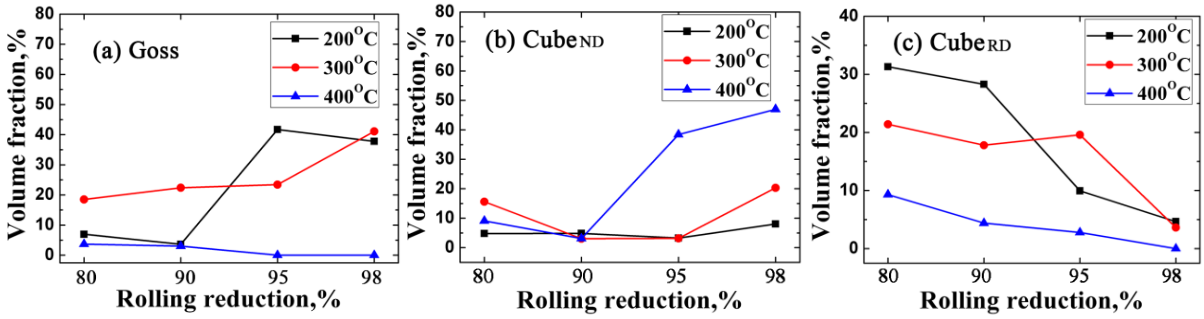

Figure 7. Evolution of the texture components (a) Goss, (b) CubeND, (c) CubeRD

4. Discussion

The present results revealed that the deformation texture of the Al-0.3%Cu alloy exhibits a strong Brass orientation (Figure 3). Usually S orientation has been reported as the strongest texture component and Copper the second strongest in Al alloys cold rolled to high strains. However, the Brass orientation was also found to be the dominant component in a hot rolled Al alloy containing fine particles, especially at high strains. It was suggested that the strong Brass texture was associated with differential dynamic grain growth, which was principally driven by different substructural energy densities in different grain orientations. The presence of Zener pinning effect made this process more selective. Deformation geometric and dynamic recovery enhanced the growth process [6]. However, nano-spaced dislocation boundaries were formed after 98% rolling in the present material. It was proposed that the dislocation boundaries were stabilized by the pinning effect of Cu solute element [7]. Therefore it is unlikely that extensive recovery occurred during rolling in the present experiment. There is no particle in the present alloy, either. One possible explanation for the strong Brass texture in the present alloy is that the Brass texture is rotated from orientations near Goss and Brass as seen in the as-forged sample (Figure 2). These orientations would rotate to Goss and Brass upon rolling, leading to an increase in the volume fraction of the Brass component. It was also proposed that Cu element in Al alloys promotes the formation of microshear bands resulting in a strong Brass texture [1]. Microshear bands were characterized by EBSD in the present alloy after cold rolled to 98% reduction [7].

Normally the main component of recrystallization texture in Al alloys is Cube. It has been suggested that deformation cube bands act as nucleation sites for the recrystallized cube grains so that the Cube orientation nucleates more frequently than other orientations [12]. The near 40°<111> relationship between the cube orientation and S deformation matrix may give the cube orientation a growth advantage compared to other recrystallization textures [8]. In this study, the Cube and $Cube_{RD}$ textures form in the 80% deformed sample annealed at 200℃. The formation of these textures may be caused by the reasons mentioned above. The $Cube_{ND}$ texture could also form in an Al alloys [9-11]. The formation of $Cube_{ND}$ was found to be associated with particles, and the 40°<111>orientation relationship between $Cube_{ND}$ and Copper enhances the development of the $Cube_{ND}$ texture. However, the $Cube_{ND}$ texture is formed only in highly deformed samples annealed at a high temperature. It is thus clear that particle stimulated nucleation is unlikely to be the dominating factor in the present results. The grain sizes are very coarse after short time annealing so that extensive grain growth might occur; and there is almost no Copper component in the material after deformation. So the formation of the present $Cube_{ND}$ texture might be caused by grain growth after recrystallization.

Instead of the Cube texture, the material exhibits a strong Goss texture in the 95% and 98% rolled samples after annealing at 200 and 300℃. It has been proposed [13] that microshear bands cut through the Cube bands and thus decrease the probability of Cube nucleation, and that the shear bands can act as nucleation sites for the Goss orientation, which strengthen the Goss texture [13]. In a recent study [4] on the same material, it was found that upon annealing both lamellar structures and shear bands nucleate Goss grains. There are ~10% volume fractions of Goss texture after rolling. Thus, these Goss orientations present in the deformed state may act as nucleation sites for Goss grains during annealing. Goss grains appear to have a growth advantage when they grow into the matrix of Brass orientations, leading to a strong Goss texture after complete recrystallization [4]. With increasing deformation strain, the stored energy increases and the critical nucleation size decreases. Therefore the nucleation of the Goss orientation during annealing increases with an increase in the rolling strain. As a result, the intensity of the Goss texture is high in annealed samples deformed to high strain.

5. Summary

An Al-0.3% Cu alloy was cold rolled to 80, 90, 95 and 98% reductions in thickness, and subsequently annealed at different temperatures until completely recrystallized. The following conclusions are reached:

- The cold-rolled material is characterized by a rolling texture with a strong Brass component.

- A $Cube_{RD}$ texture was formed in the 80% rolled sample annealed at 200℃. The volume fraction of the $Cube_{RD}$ decreases with increasing deformation strain and annealing temperature.
- A strong Goss texture was developed especially in 95 and 98% rolled samples after complete recrystallization at 200℃ and 300℃. The intensity of Goss texture increases as the rolling strain is increased.

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