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Annealing character of cartridge brass

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ABSTRACT

Cu-30%Zn alloy is known as cartridge brass and it is widely used for cartridge cases, which are produced from hot rolled sheet by deep-drawing process at normal room temperature. Intermediate annealing is needed to ensure low work-hardening during drawing and to minimize the forming related problem of cartridge brass. Laboratory muffle furnace is used to carry out the annealing heat-treatment of deformed cartridge brass. An annealing heat treatment temperature range of (300-600)^{0}C is used to develop structure after recovery, partial recrystalization, complete recrystallization and grain growth. The annealed structures are characterized by optical microscope equipped with microstructure analysis software. The quantitative microstructure details like average grain size and grain size distributions are measured. The texture characterization of annealed samples is done by pole figure measurement by X-ray texture Goniometer and subsequent texture analysis is performed by LaboTex-Edu texture analysis software. The structure and texture details show that at lower temperature recovery occurs while at higher temperature recrystallization with trace of grain growth occurs. The structure and texture in the intermediate temperature range is contributed by recovery and partial recrystallization.

KEYWORDS

Annealing;
Cartridge brass;
Microstructure and texture.

BACKGROUND

The cartridge case made up with cartridge brass is drawn products, which is produced from hot rolled sheet by deep-drawing process at room temperature[1]. This drawing process needs high ductility and toughness to ensure low work-hardening and to minimize forming related problem[2]. The softening mechanism to induce ductility and toughness needed for any efficient drawing process is known as annealing. The annealing serves as the process for micro-mechanisms such as recovery, recrystallization and grain growth at elevated temperature[3-5]. The recovery is basically the lowering of dislocation density and discontinuous recrystallization is defined as the formation of strain free grains by high angle grain boundary movement, which is driven by deformation energy of stored dislocations[3-5]. The grain growth occurs minimizing the surface energy of grain boundary by enlargement of recrystallized grains[3-5]. The 70% Cu and 30% Zn, Cartridge brass is a single phase alloy, which is also known as α-brass[1]. The development of microstructure constituents such as grain size, grain size distribution and bulk texture of this alloy is a subject of elaborate research because these recovery, recrystallization and grain growth do not follow similar rules for all metals and alloys and they depends on the many variables such as stages of deformations, temperature, heating rate and composition and inherent properties such as stacking fault energy of metals and alloys[3,6-10]. The sequence of occurrence of recovery, recrystallization and grain growth is also not clear during annealing[3].

ANNEALING

Laboratory muffle furnace was used to carry out the annealing heat-treatment of deformed cartridge brass. An annealing heat treatment temperature range of (300-600)°C was used (TABLE 1) to develop structure after recovery, partial recrystalization, complete recrystallization and grain growth. The heating rate of the furnace was 10°C per minute. The holding time at the annealing temperature was 600 seconds for all samples and the annealed samples was subsequently quenched in water after annealing.

TABLE 1 : % Prior reduction, annealing temperature and time

% Cold Reduction Prior to Annealing	Annealing Temperature (°C)				Annealing Time (second)
15	300	400	500	600	600
30	300	400	500	600	600
40	300	400	500	600	600
50	300	400	500	600	600

RESULTS

Microstructure characterization

The annealed structures are characterized by optical microscope equipped with microstructure analysis software. The quantitative microstructure details like average grain size and grain size distributions are measured. The average values of linear intercept grain size (L) of samples annealed at 500°C, 550°C and 600°C are compared (Figure 1), which says that average values of linear intercept grain size (L) first increases with degree of cold reduction prior to annealing followed by the drop in average grain size. The average grain size of the rolled samples annealed at 500°C increases up to

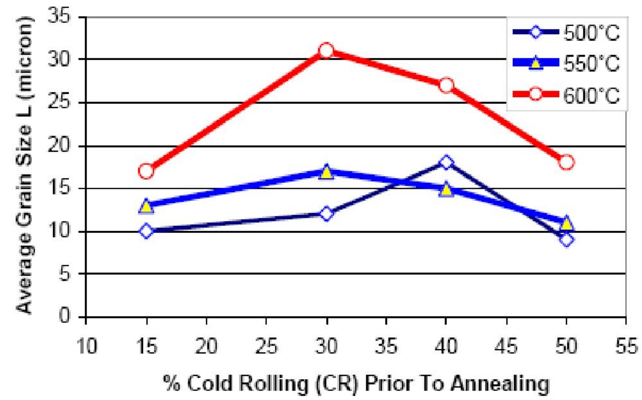

Figure 1 : Variation of average linear intercept grain size (L in rolling direction) with annealing temperature

40% prior cold reduction and then drops, while the grain size of the rolled samples annealed at 550°C and 600°C increases up to 30% cold reduction and then drops. The generalized trend of variation of grain size with annealing temperature at a particular degree of prior cold reduction says that average grain size increases with annealing temperature. The average grain size of 50% rolled and annealed sample becomes comparable to that of 15% rolled and annealed samples for all three annealing conditions.

The grain size (L) distribution (Figure 2(i)) compares the number frequency versus L of rolled samples annealed at 500°C. The 15%, 30% and 50% rolled samples show log normal distribution. The population of larger size grain increases with 30% and 40% rolled samples prior to annealing. The distributions of 15% and 50% rolled samples are quite similar.

The rolled samples annealed at 550°C show grain size distributions (Figure 2(ii)) very near to the log normal distribution. The number frequency of larger size grains increases with 30% and 40% rolled samples prior to annealing.

The log normal distribution found in 15% and 50%

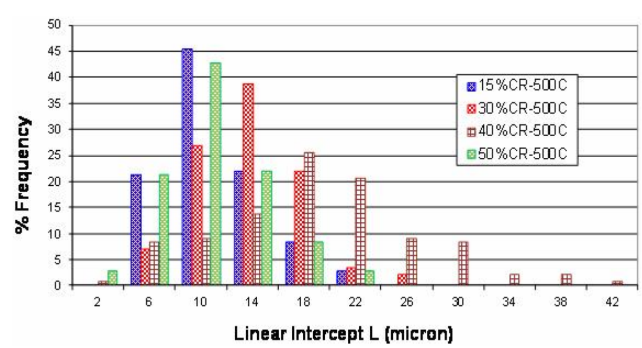

Figure 2(i) : Linear intercept grain size (L in rolling direction) distribution of samples annealed at 500°C

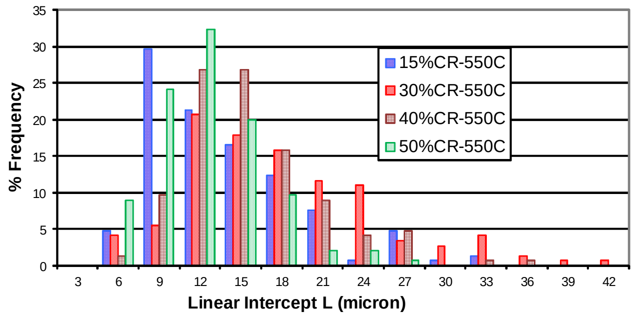

Figure 2(ii) Linear intercept grain size (L in rolling direction) distribution of samples annealed at 550°C

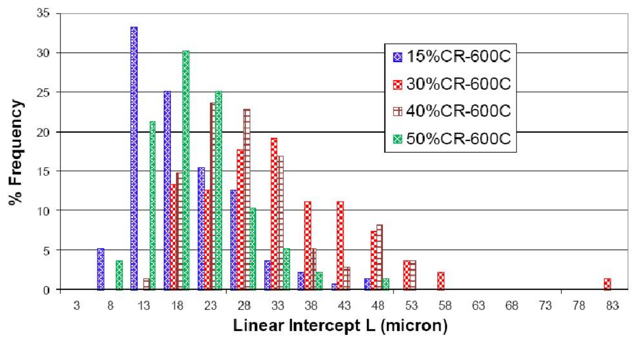

Figure 2(iii) : Linear intercept grain size (L in rolling direction) distribution of samples annealed at 600°C

rolled samples annealed at 600°C is shown in Figure 2(iii). The 30% and 40% rolled samples annealed at 600°C are associated with higher frequency of larger grain size and the character of distributions also differs from log normal distribution.

Bulk texture measurement

The crystallographic bulk textures of the samples are measured by X-ray texture Goniometer. The qualitative and quantitative bulk textures of annealed samples are denoted by orientation distribution functions (ODF) and texture strength of ideal orientations derived from 111, 200 and 220 measured pole figures using LaboTex-Edu texture analysis software. The locations of ideal orientations in orientation distribution function are shown in Figure 3(i).

A. Annealing

The orientation distribution functions of 15% rolled and annealed samples are shown in Figure 3(ii)-(v), which show that

(i) increase in rolling texture intensity after annealing at 300°C and 400°C
(ii) randomization of texture after annealing at 500°C
(iii) development of brass and cube component after annealing at 600°C.

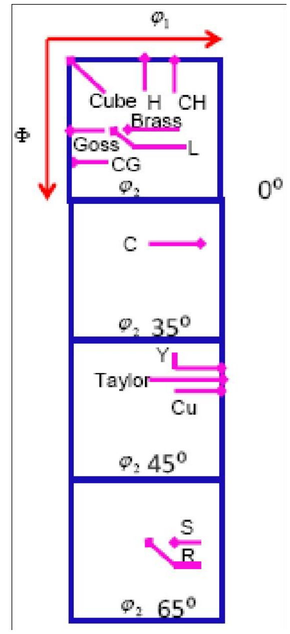

Figure 3(i) : Ideal texture orientations in orientation distribution function

The volume % of the ideal texture orientations of 15% rolled and annealed samples are shown in TABLE 2(i). The texture strengths of Cube, Brass, Cu, Taylor, CG, Y and C first increase up to annealing temperature 400°C, decrease to their minimum strength at 500°C and increase again at annealing temperature 600°C. The strengths of S, R and Goss gradually decrease up to annealing at 500°C and increase again at 600°C. The texture volume strengths of H and CH orientations first increase up to annealing temperature 500°C and then decrease at 600°C while the strength of L orientation first increases at 400°C and then gradually decreases till 600°C.

The orientation distribution functions of 30% rolled and annealed samples are shown in Figure 4 (i)-(iv), which show that

(i) increase in rolling texture intensity after annealing at 300°C.
(ii) randomization of texture after annealing at 400°C and 500°C.
(iii) development of Cube and Brass components after annealing at 600°C.

The volume % of the ideal texture orientations of 30% rolled and annealed samples are shown in TABLE 2 (ii). Annealing increases the strength of Cube component. The strengths of Brass, Goss and Y components first reduce up to 500°C and then increase at 600°C while the strengths of S, R, CG and C compo-

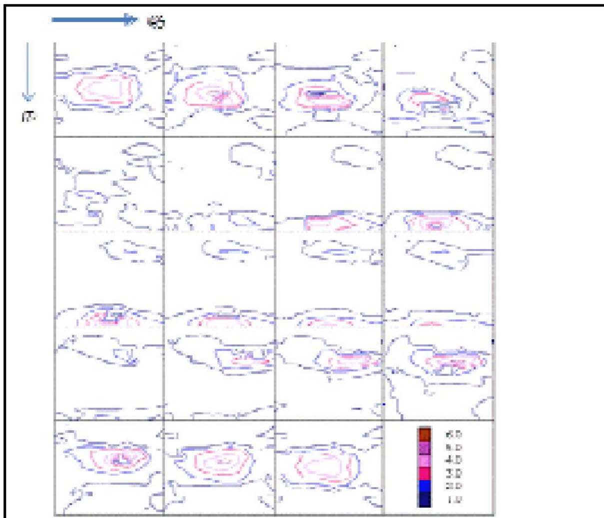

Fig. 3 (ii) 15% Cold Rolling + 300°C Annealing

Figure 3(ii) : 15% Cold rolling + 300°C annealing

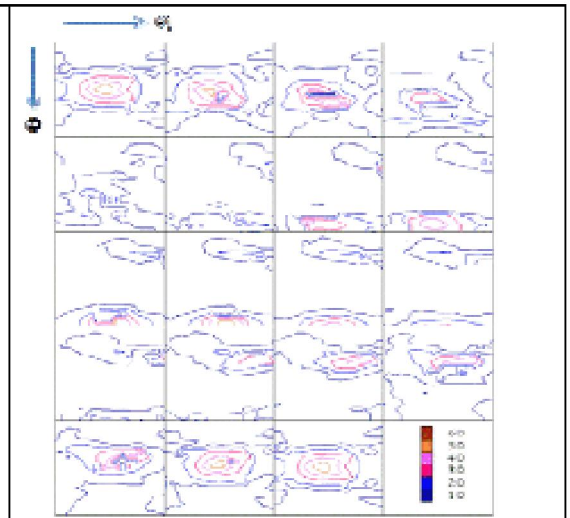

Fig. 3 (iii) 15% Cold Rolling + 400°C Annealing

Figure 3(iii) : 15% Cold rolling + 400°C annealing

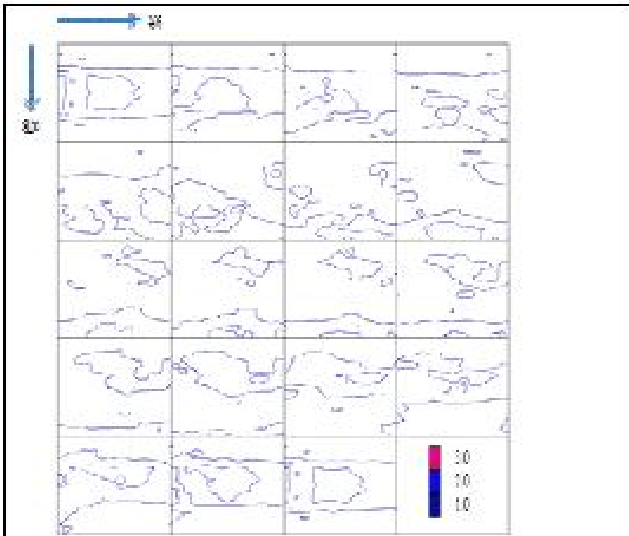

Fig. 3 (iv) 15% Cold Rolling + 500°C Annealing

Figure 3(iv) : 15% Cold rolling + 500°C annealing

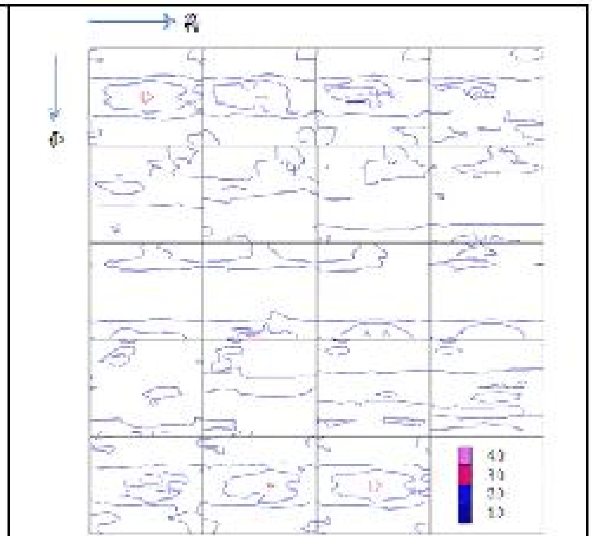

Fig. 3 (v) 15% Cold Rolling + 600°C Annealing

Figure 3(v) : 15% Cold rolling + 600°C annealing

Figure 3(ii)-(v) : Orientation distribution functions of 15% rolled and annealed texture at (ii) 300° C, (iii) 400° C, (iv) 500°C and (v) 600°C

nents first reduce at 400°C and then increases up to 600°C. The volume % of H and CH orientations increases up to 500°C and reduces at 600°C. The strength of L and Taylor orientations reduces with the increase in annealing temperature while the strength of Cu does not show any steady trend.

The orientation distribution functions of 40% rolled and annealed samples are shown in Figure 5 (i)-(iv), which show that

(i) increase in rolling texture intensity after annealing at 300°C.

(ii) randomization of texture after annealing at 400°C and 500°C and formation of Cube and rotated Cube components.

(iii) preferred development of transverse direction rotated Cube and Brass components after annealing at 600°C.

The volume % of the ideal texture orientations of

TABLE 2(i) : Texture strength of 15% rolled ideal texture orientations after annealing

Orientation {h k l}<u v w>	300°C	400°C	500°C	600°C
Cube {001}<100>	1.45	1.58	1.36	1.50
Brass {110}<112>	6.82	7.44	3.06	4.84
Cu {112}<111>	1.80	1.83	1.10	1.30
R {123}<412>	6.13	6.00	3.12	4.00
S {123}<643>	7.32	7.26	3.26	4.14
Goss {110}<001>	3.00	2.75	2.52	3.36
Taylor {4411}<11118>	2.20	2.30	1.24	1.25
H{001}<110>	0.83	0.90	1.16	1.00
CG{021}<100>	4.62	4.83	3.05	3.72
CH{001}<120>	1.12	1.14	1.51	1.30
Y {011}<522>	6.37	6.87	3.00	4.56
L {113}<332>	2.10	2.21	1.25	1.22
C {236}<385>	4.26	4.60	2.23	2.84

TABLE 2(ii) : Texture strength of 30% rolled ideal texture orientations after annealing

Orientation {h k l}<u v w>	300°C	400°C	500°C	600°C
Cube {001}<100>	1.25	1.40	1.50	1.88
Brass {110}<112>	6.90	2.86	2.56	7.07
Cu {112}<111>	2.04	1.07	1.24	1.11
R {123}<412>	7.40	2.85	3.03	5.00
S {123}<643>	8.43	2.85	2.85	4.92
Goss {110}<001>	3.37	2.47	2.30	2.80
Taylor {4411}<11118>	2.15	1.38	1.37	1.22
H{001}<110>	0.90	1.11	1.20	1.12
CG{021}<100>	5.30	2.86	3.00	3.40
CH{001}<120>	1.35	1.70	1.70	1.46
Y {011}<522>	7.06	2.75	2.62	6.88
L {113}<332>	2.02	1.44	1.40	1.23
C {236}<385>	4.23	2.04	2.16	2.81

40% rolled and annealed samples are shown in TABLE 2(iii). Annealing increases the strength of Cube component. The strengths of Brass, Cu, Goss, S, R, CG, C, L, Taylor and Y components first reduce up to 500°C and then increase at 600°C. The volume % CH orientations increases up to 400°C and reduces till 600°C while the volume % H does not show any steady trend.

The orientation distribution functions of 50% rolled and annealed samples are shown in Figure 6 (i)-(iv), which show that

(i) increase in rolling texture intensity after annealing at 300°C.

(ii) randomization of texture after annealing at 400°C and 500°C and formation of Cube and rotated Cube components by recrystallization.

(iii) preferred development of Cube, transverse direction rotated Cube and Brass components at 600°C.

The volume % of the ideal texture orientations of 50% rolled and annealed samples are shown in TABLE 2(iv). Annealing gradually increases the strength of Cube component. The strengths of Brass and Y components first reduce up to 500°C and then increase at 600°C. The strength of Goss and CG texture components fist reduce at 400°C and then increase till 600°C. The volume % H and CH orientations increase up to annealing temperature 600°C. The texture strength Cu,

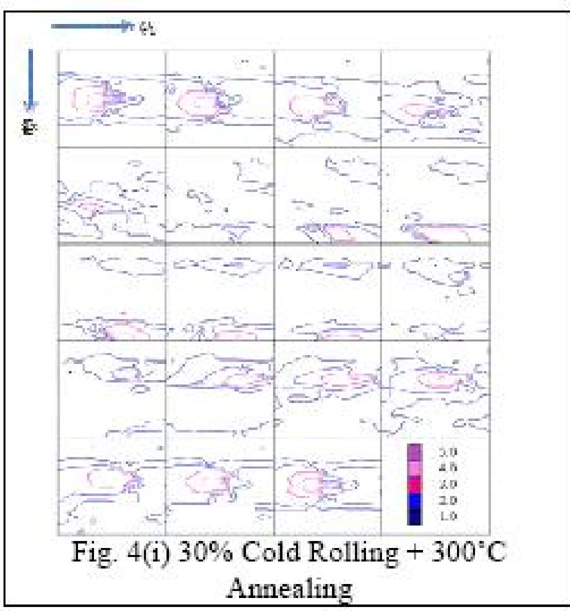

Figure 4(i) : 30% Cold rolling + 300°C annealing

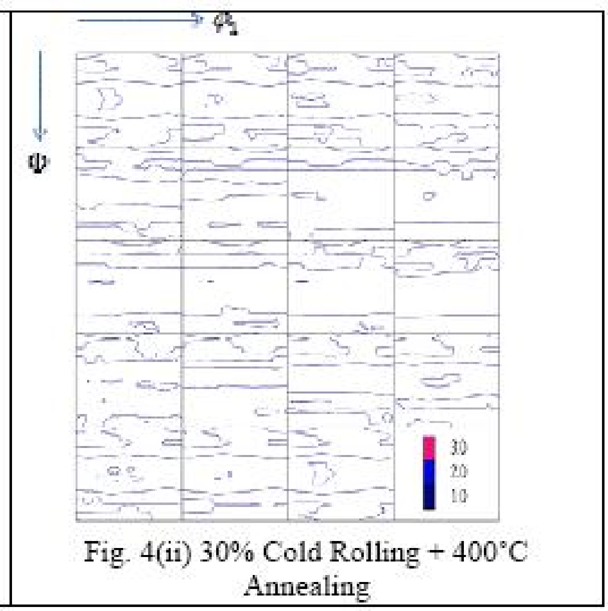

Figure 4(ii) : 30% Cold rolling + 400°C annealing

R, S, Taylor, C and L does not show any steady trend.

Hardness data

The hardness in Vicker's scale (HV) of cold rolled and annealed samples are shown in TABLE 3. The hardness of as received sheet was 145 HV. The cold rolling 15%, 30%, 40% and 50% gradually increases the harness of the cartridge case alloy while annealing reduce the hardness. The hardness depends on the annealing temperature. The higher the annealing temperature the lower is the hardness for each prior cold rolled samples except the 15% prior cold rolled and annealed samples which shows similar hardness after annealing at 300°C and 350°C. All 600°C annealed samples have shown near about similar hardness with the variation of 10 HV.

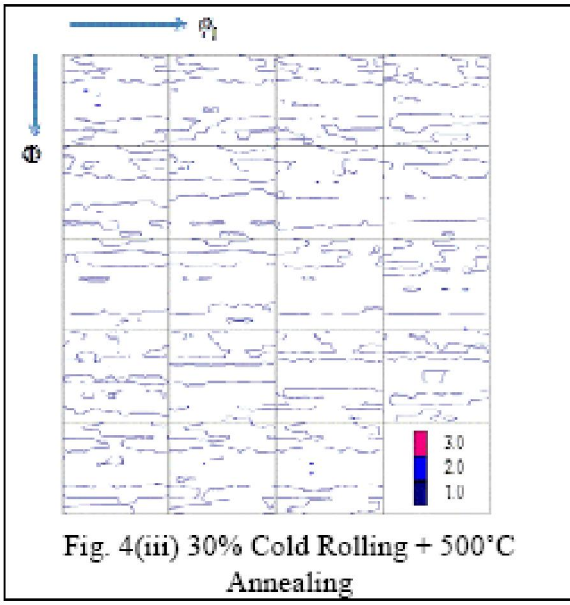

Figure 4(iii) : 30% Cold rolling + 500°C annealing

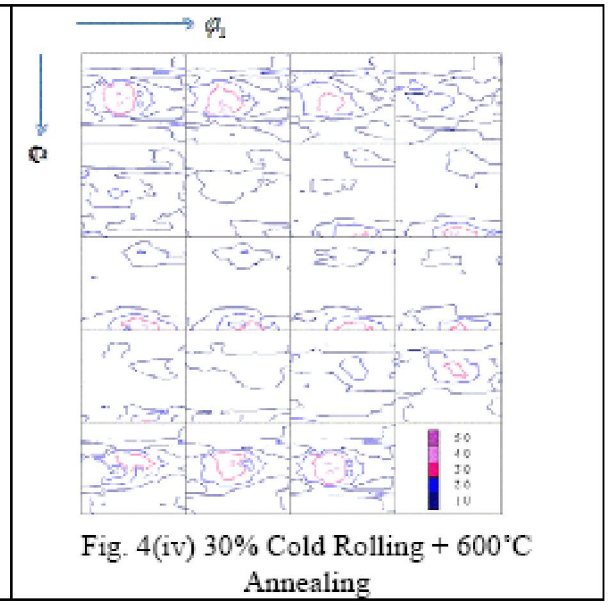

Figure 4(iv) : 30% Cold rolling + 600°C annealing

Figure 4 : Orientation distribution functions of 30% rolled and annealed texture at (i) 300°C, (ii) 400°C, (iii) 500°C and (iv) 600°C

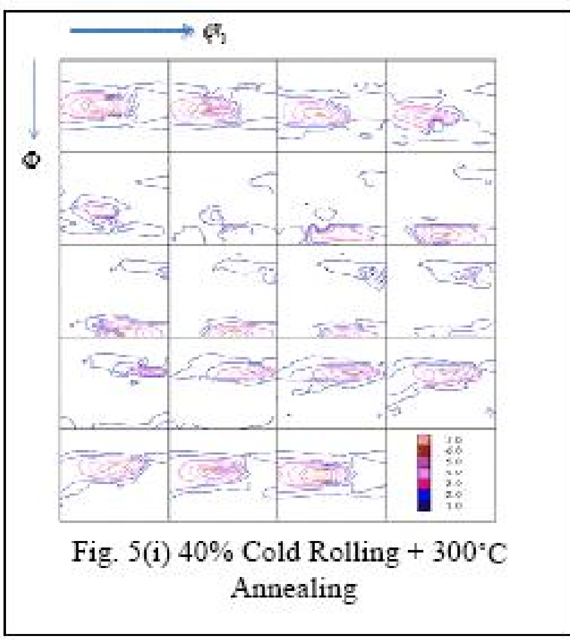

Figure 5(i) : 40% Cold rolling + 300°C annealing

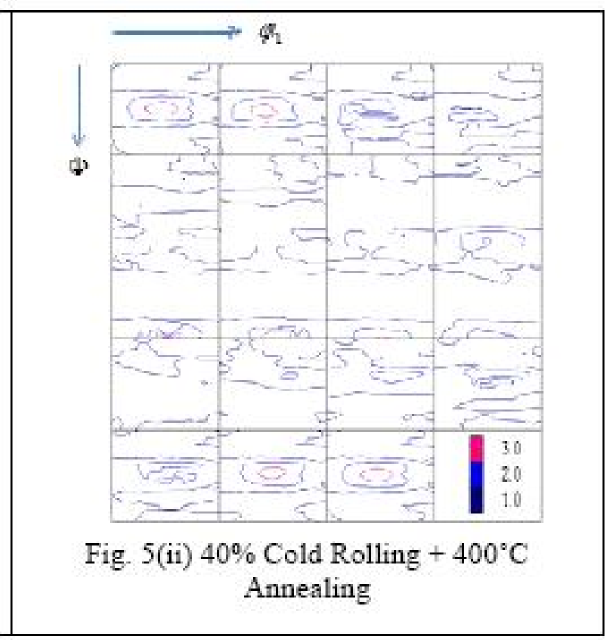

Figure 5(ii) : 40% Cold rolling + 400°C annealing

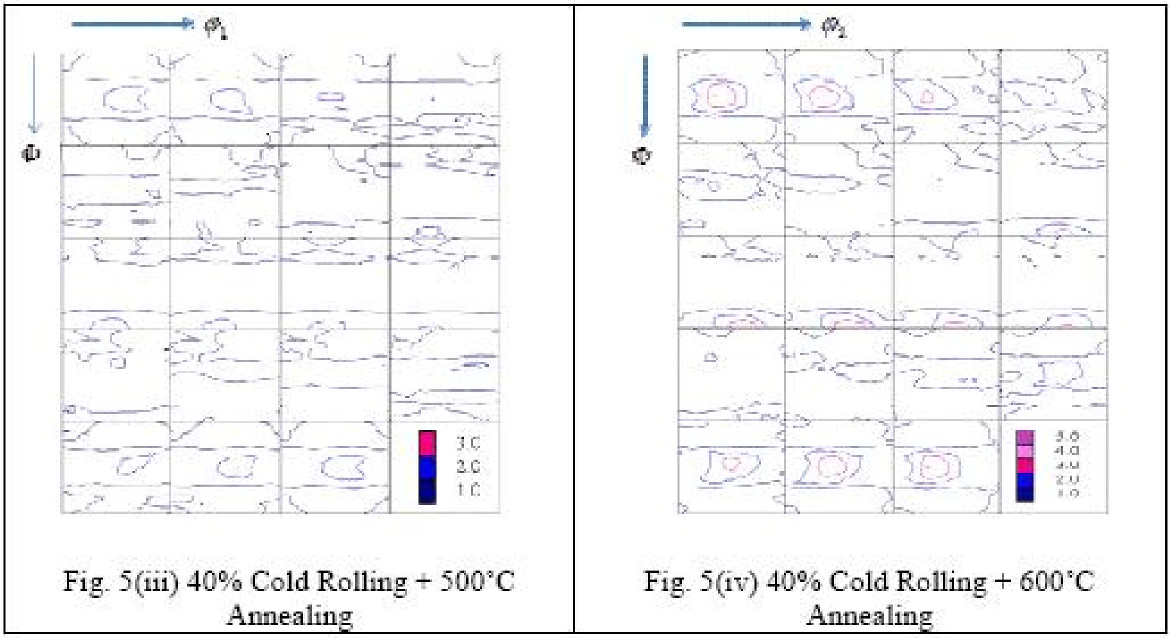

Figure 5(iii) : 40% Cold rolling + 500°C annealing **Figure 5(iv) : 40% Cold rolling + 600°C annealing**

Figure 5 : Orientation distribution functions of 40% rolled and annealed texture at (i) 300°C, (ii) 400°C, (iii) 500°C and (iv) 600°C

TABLE 2(iii) : Texture strength of 40% rolled ideal texture orientations after annealing

Orientation {h k l}<u v w>	300°C	400°C	500°C	600°C
Cube {001}<100>	0.84	1.60	1.65	1.85
Brass {110}<112>	10.00	5.00	3.26	4.85
Cu {112}<111>	2.86	1.21	1.00	1.21
R {123}<412>	8.44	4.50	3.32	4.10
S {123}<643>	10.65	4.34	3.46	4.10
Goss {110}<001>	3.55	2.74	2.16	2.45
Taylor {4411}<11118>	2.85	1.36	1.10	1.15
H{001}<110>	0.57	1.06	1.00	1.06
CG{021}<100>	5.16	3.31	3.16	4.00
CH{001}<120>	0.86	1.54	1.46	1.43
Y {011}<522>	10.00	4.60	3.00	4.23
L {113}<332>	2.55	1.36	1.10	1.12
C {236}<385>	3.80	2.75	2.65	3.50

TABLE 2(iv) : Texture strength of 50% rolled ideal texture orientations after annealing

Orientation {h k l}<u v w>	300°C	400°C	500°C	600°C
Cube {001}<100>	0.60	1.70	2.00	3.00
Brass {110}<112>	8.60	3.35	3.17	8.60
Cu {112}<111>	3.60	1.11	1.40	1.00
R {123}<412>	10.23	3.42	3.85	3.70
S {123}<643>	11.76	3.60	4.30	4.13
Goss {110}<001>	3.41	2.12	2.23	3.00
Taylor {4411}<11118>	2.60	1.40	1.65	1.36
H{001}<110>	0.55	1.20	1.33	1.60
CG{021}<100>	3.75	2.80	3.16	3.46
CH{001}<120>	0.80	1.82	2.00	2.06
Y {011}<522>	8.80	3.10	2.75	8.75
L {113}<332>	2.20	1.36	1.60	1.42
C {236}<385>	3.14	2.75	3.42	2.75

DISCUSSION

The average values of linear intercept grain size (L) all rolled samples annealed at 500°C, 550°C and 600°C first increases with degree of cold reduction prior to annealing followed by the drop in average grain size. The average grain size of the rolled samples annealed at 500°C increases up to 40% prior cold reduction and then drops, while the grain size of the rolled samples annealed at 550°C and 600°C increases up to 30% prior cold reduction and then drops. This shows the trends of partial recrystallized structure. The recrystallization produces strain free grains and reduces the average grain size. The first increase in grain size is due to presence of majority of rolled and recovered elongated grains in partially recrystallized structure which is fol-

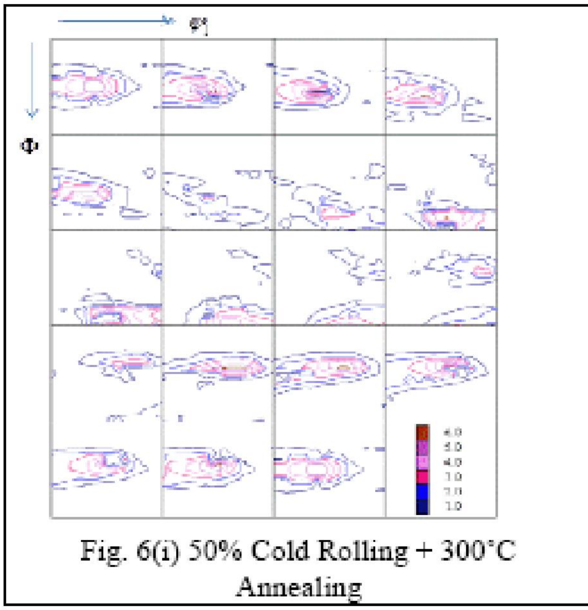

Figure 6(i) : 50% Cold rolling + 300°C annealing

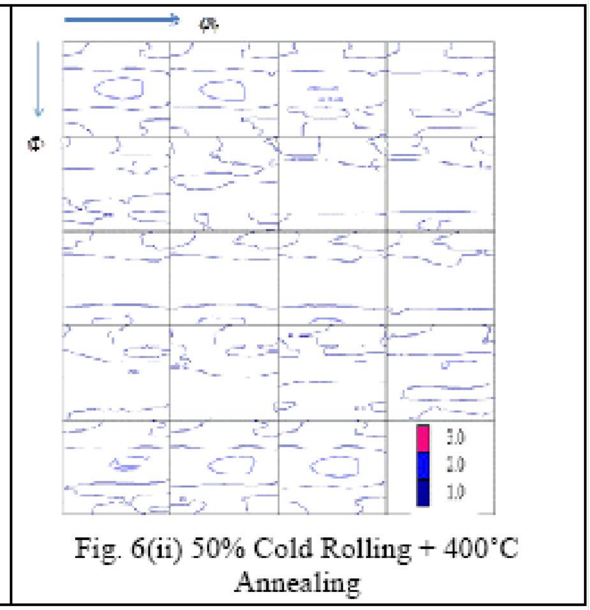

Figure 6(ii) : 50% Cold rolling + 400°C annealing

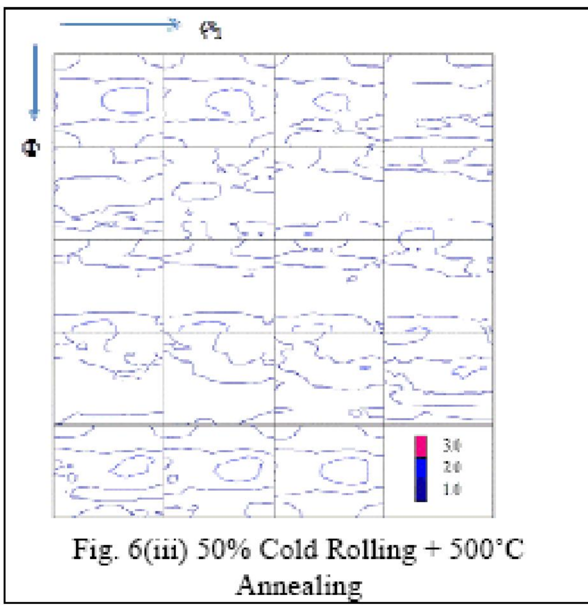

Figure 6(iii) : 50% Cold rolling + 500°C annealing

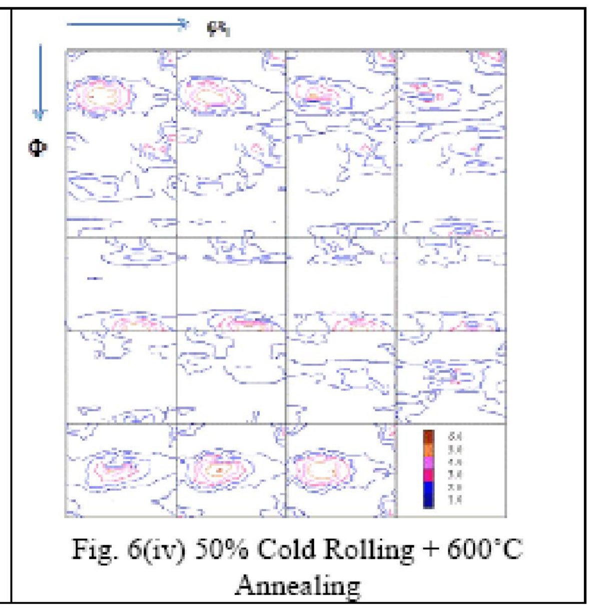

Figure 6(iv) : 50% Cold rolling + 600°C annealing

Figure 6 : Orientation distribution functions of 50% rolled and annealed texture at (i) 300°C, (ii) 400°C, (iii) 500°C and (iv) 600°C

lowed by the reduction of grain size by the production of majority of recrystallized grains. The increase in annealing temperature from 500°C to 550°C and 600°C increases the mobility of high angle grain boundary surrounding the nuclei and needs less stored energy associated with 30% rolling reduction to on set nucleation and growth of recrystallization than 500°C annealing, which needs 40% rolling reduction as driving force for nucleation and growth of majority of grains. The trend of variation of grain size with annealing temperature at a particular degree of prior cold reduction says that average grain size increases with annealing temperature should be due to partial recrystallization is also associated with trace of grain growth. The average grain size of 50% rolled and annealed sample becomes comparable to that of 15% rolled and annealed samples for all annealing conditions should be due to complete recrystallization at 50% rolled samples with the trace of

TABLE 3 : Deformed and annealed hardness

Sample	15% Rolled	30% Rolled	40% Rolled	50% Rolled
Deformed	175	180	186	190
300 °C	160	150	175	170
350 °C	160	135	160	150
400 °C	150	130	140	120
450 °C	120	120	120	105
500 °C	100	90	105	100
550 °C	86	80	86	90
600 °C	70	75	73	80

TABLE 4 : Texture trends after annealing

Annealing Temperature	15% Rolled	30% Rolled	40% Rolled	50% Rolled
300°C	Increase in Rolling Texture	Increase in Rolling Texture	Increase in Rolling Texture	Increase in Rolling Texture
400°C	Increase in Rolling Texture	Random Texture with Cube and Rotated Cube	Random Texture with Brass, Cube and Rotated Cube	Random Texture with Cube and Rotated Cube
500°C	Random Texture	Random Texture with Cube and Rotated Cube	Random Texture with Cube and Rotated Cube	Random Texture with Cube and Rotated Cube
600°C	Random Texture with Cube and Brass	Textured with Brass and Cube	Textured with Brass and Cube	Textured with Brass and Cube

grain growth. These inferences are also supported by the grain size (L) distributions obtained after annealing at 500°C, 550°C and 600°C.

The trends of texture of annealed samples are shown in TABLE 4. The texture trends have five distinct features such as

(i) Increase in rolling texture
(ii) Random texture
(iii) Random texture with Cube and Rotated Cube
(iv) Random texture with Brass, Cube and Rotated Cube
(v) Textured with Brass and Cube.

The increase in rolling texture is found in all rolled samples after annealing at 300°C and in 15% rolled sample after annealing at 400°C also. The increase in rolling texture is due to annihilation of dislocations during recovery, which reduces the scattering of X-ray. The random texture (of intensity 2-3 times random) develops when majority of grains get dissimilar orientations and that is due to partial recrystallization. The formation of high percentage of Cube and Rotated Cube oriented grains produces random with Cube and Rotated Cube texture while the formation of Brass oriented grains also during partial recrystallization produces Random texture with Brass, Cube and Rotated Cube orientation. All rolled samples except the 15% rolled sample produce either random texture with Cube and Rotated Cube or random texture with Brass, Cube and Rotated Cube after annealing at 400^{0}C and 500^{0}C. The preferred development of Brass and Cube oriented grains are found after annealing at 600^{0}C for 30%, 40% and 50% rolled samples and that should be due to the preferential grain growth of Brass and Cube oriented grains.

The trends of nucleation for fcc metals and alloys are listed in TABLE 5. This trends show both the discontinuous and in-situ (continuous) recrystallizations. The stable remnant parts of the original Cube band after deformation contributes in Cube nuclei, meta-stable rolling direction rotated Cube band generates CG and Goss nuclei (with the limit of 45° rolling direction rotation), slight orientation rotation near the grain boundary of S components produce R nuclei while normal direction rotated Cube and shear band in deformation heterogeneities develop CH and H texture orientations respectively by discontinuous recrystallization. The possibility of occurrence of continuous or in-situ recrsytallization in fcc metals and alloys depending upon the annealing temperature, heating rate is also re-

TABLE 5 : Trends of nucleation and preferred sites in fcc metals and alloys[11,12]

Orientation	Sites
Cube	Deformed Cube Band
CG and Goss	Transition Band (Rolling Direction rotated Cube)
Brass, S, Copper	Deformation Texture Orientations (in-situ recrsytallization)
R	Grain-boundary
CH	Normal Direction (ND) rotated Cube
H	Shear Texture (45^0 ND rotated Cube)

ported[2,3,12] to develop Brass, Cu and S components predominantly by nucleation (extended recovery or recrystallization in situ) without grain growth. The in-situ recrystallization is primarily governed by the intrinsic property of fcc metals and alloys such as stacking fault energy. The increase in rolling texture which occurs after annealing at 300°C should not be addressed as continuous recrystallization because the hardness measurement shows high hardness near about (150-175) HV.

The elevated temperature (600 °C) annealing develops textured structure with high strength of Cube and Brass components. The Brass component is formed by deformation and also annealing. The possibility of getting random texture by inter-annealing, which is found in AA5XXX aluminium alloy[13] is less in Brass due to this fact. The degree of isotropic property depends on the crystallographic texture. The dissimilar orientations of grains associated with random texture tend to result in the isotropic property[14] whereas the rolling texture and Cube recrystallization textures in high stacking fault energy face centered cubic metals and alloys are associated with forming problems such as earing during deep drawing[15-16].

SUMMARY

The average grain size of the rolled samples annealed at 500°C increases up to 40% cold reduction and then drops, while the grain size of the rolled samples annealed at 550°C and 600°C increases up to 30% cold reduction and then drops due to initial partial recrystallization followed by complete recrytallization.

The trend of variation of grain size with annealing temperature shows that average grain size increases with annealing temperature should be due to partial recrystallization is also associated with trace of grain growth.

The average grain size of 50% rolled and annealed sample becomes comparable to that of 15% rolled and annealed samples for all annealing conditions should be due to complete recrystallization at 50% rolled samples with the trace of grain growth. These inferences are also supported by the grain size (L) distributions obtained after annealing at 500°C, 550°C and 600°C.

The trends of texture of annealed samples have five distinct features such as

(i) Increase in rolling texture,
(ii) random texture,
(iii) random texture with Cube and rotated Cube,
(iv) random texture with Brass, Cube and rotated Cube
(v) textured with Brass and Cube

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