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Effect of abrasives on the glossiness and reflectance of anodized aluminum alloys

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Abstract Blasting can eliminate or change the surface texture of as-rolled aluminum alloy by indentation to roughen the alloy's surface. We investigated the effects of the blasting conditions on the glossiness and reflectance of Al1050-H16 and Al5052-H32 alloys in this study. As-rolled sheets were blasted at various pressures, and then removed for sequential cleaning, chemical polishing, and anodizing steps. After each step the samples were measured by micro-TRI-gloss meter and spectrophotometer to compare the effects produced by the abrasive powders and processing variables. Polyhedral alumina and round iron powders were used as the blasting media. The glossiness (Gs(60°)) decreased as the root mean square roughness (Rq) increased, regardless of the shape of the abrasive powders. The abrasives powders could cause wear and/or fracturing during the blasting process as well as fine debris, which could become embedded in the blasted surface. When an aluminum alloy was blasted with iron powders, the glossiness value after alkaline etching and chemical polishing was greater than that after being blasted with alumina; while the anodized Al5052-H32 alloy's surface became more yellowish in color.

Introduction

The unique and graceful appearance of the surface coating of aluminum alloys is fascinating. This surface coating is not only desirable for its high-quality cosmetic appearance but also enhances corrosion resistance. Anodizing is a very common process that gives great advantages in terms of productivity and economics, associated with the enhancement of the attractive cosmetic appearance of the product. The cosmetic appearance can be adjusted by the pre-treatment and processing parameters adopted during the anodizing process. The commonly used pre-treatments include cleaning, etching with caustic soda, blasting, and chemical or electrochemical polishing.

Various abrasives, such as alumina, iron abrasives, or glass beads, can be used in the blasting of aluminum alloys. The abrasives themselves encounter severe wear and tear during the blasting process, which is affected by the size and shape of the abrasive, the surface hardness of the material being treated, and the angle of impingement [1]. Shot blasting is one simple and efficient measure to improve the fretting fatigue life [2]. Depending on the type of grits used, the composition of the treated surface can be slightly changed, due to residues from the abrasive media [3].

Yonehara et al. investigated the effect of surface roughness on the glossiness of 5052 aluminum alloys. They found that the glossiness value increased slightly as the arithmetical mean roughness (Ra) decreased. A surface with low amplitudes and short roughness wavelengths had high glossiness values [4]. The lightness value of the surface L* depends on the topography of the surface, where the relationship of L* versus Ra is inversely proportional to that of the glossiness versus the Ra [5–7]. For an anodized 5052 aluminum alloy, the hue angle of the colored anodized surface is influenced by the arithmetical mean roughness (Ra) [8].

According to the description of ASTM D 523-89, gloss is the relative luminous reflectance of a specimen in the

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mirror direction. The gloss value is determined from the relation between the light source, the surface, and the observer. If the deviation produced from the light source and the observer is limited, the gloss is mainly influenced by the surface properties, such as the material, surface topography, degree of transparency, and substrate [9]. The glossiness value of a given material is closely related to its surface roughness [10]. Pre-treatment, including alkaline etching, blasting, and chemical polishing, has a great effect on the glossiness and cosmetic appearance of anodized aluminum alloys (Al1050 and Al5052 alloy), which will be discussed in this study.

Experimental procedure

As-received Al1050-H16 (coded 1050) and Al5052-H32 (coded 5052) alloy sheets were cleaned with a degreasing agent. After rinsing with tap water and dried in hot air, the sheet metals were shot blasted by spherical iron powders and polyhedral alumina powders; see Figs. 1a and 2a. The iron powders were made of reduction process from raw materials (iron ore, coke, and lime), milling and purification for getting blasting grade powders and are commercial product imported from Japan. The sieve analyses of virgin alumina and iron powders are shown in Figs. 1b and 2b, respectively. The shot blasting conditions are as follows: 300 mm standoff distance; the nozzle acts normally to the blasted surface, with blasting pressures from 1 to 4.5 kg/cm^2. After shot blasting, a forced air stream was used to clean the blasted surface. The sheet samples were removed for sequential alkaline etching and desmutting in 5% w/w NaOH and 50% v/v HNO_3 solutions, respectively.

After alkaline etching, samples were chemically polished in a solution consisting of a mixture of 77.5% v/v ortho-phosphoric acid, 16.5% v/v sulfuric acid, 6% v/v nitric acid. The sheet samples were rinsed with distilled water after polishing and then removed for galvanostatical anodization in a 15% w/w H_2SO_4 electrolyte solution for 1,200 s. The anodized sheets were then rinsed and sealed in (95 °C) hot water for 1,800 s. After blasting, polishing, and anodizing, the blasted sheets were removed and the reflectance and glossiness of specimens were measured by spectrophotometer CM-503i and mirror-TRI-gloss meter (BYK-Gardner).

The reflectance of a surface can be evaluated by CIE (*Commission Internationale d'Eclairage*) L*a*b* color space defined method developed in 1976; ASTM D2244-79. The first digit represents the lightness of the color (L*, where L* = 0 indicates black and L* = 100 indicates white); the second digit indicates colors between magenta and green (a*, where negative values indicate green while positive values indicate magenta) and the last digit indicates colors between yellow and blue (b*, where negative values indicate blue and positive values indicate yellow).

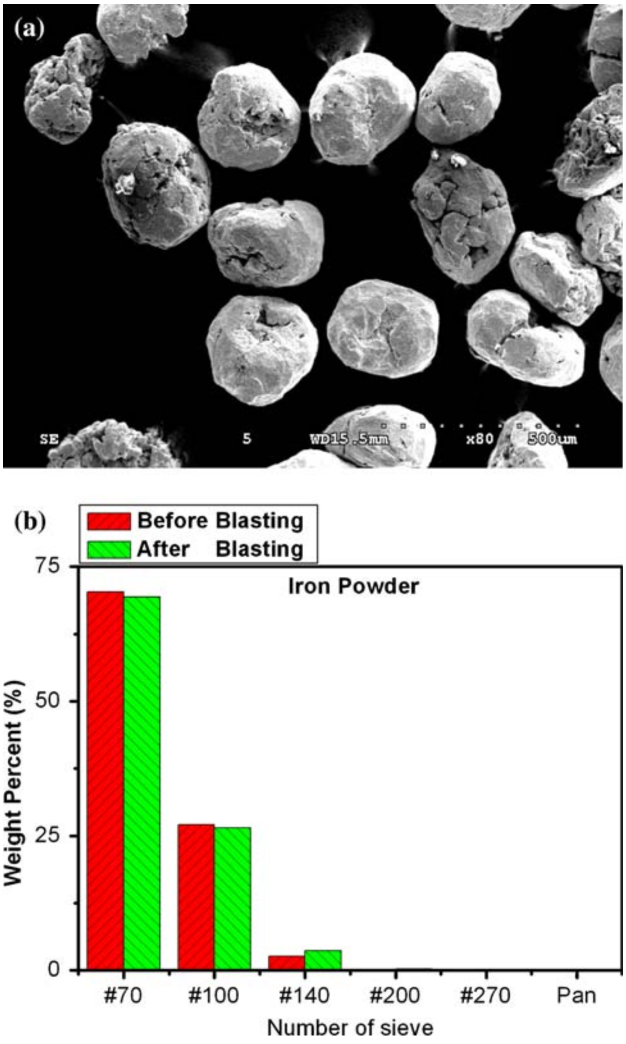


Fig. 1 (**a**) Morphology of the iron powders; (**b**) sieve analyses before and after blasting treatment

For glossiness measurements, CIE standard light source at geometries of 20, 60 and 85° was applied. If glossiness values were between 10 and 70, the 60° was adopted for measurement. When the glossiness values measured at 60° were higher than 70, then a 20° light source should be used. When the glossiness values measured at 60° were lower than 10, then it is suggested the 85° be used.

After measurement of the glossiness and reflectance, the blasted samples were removed and their surface morphology observed by a LEO 1530 Field Emission Scanning Electron Microscope (SEM). The constituents of embedded blasting powders debris were detected by energy dispersive X-ray analysis (EDX).

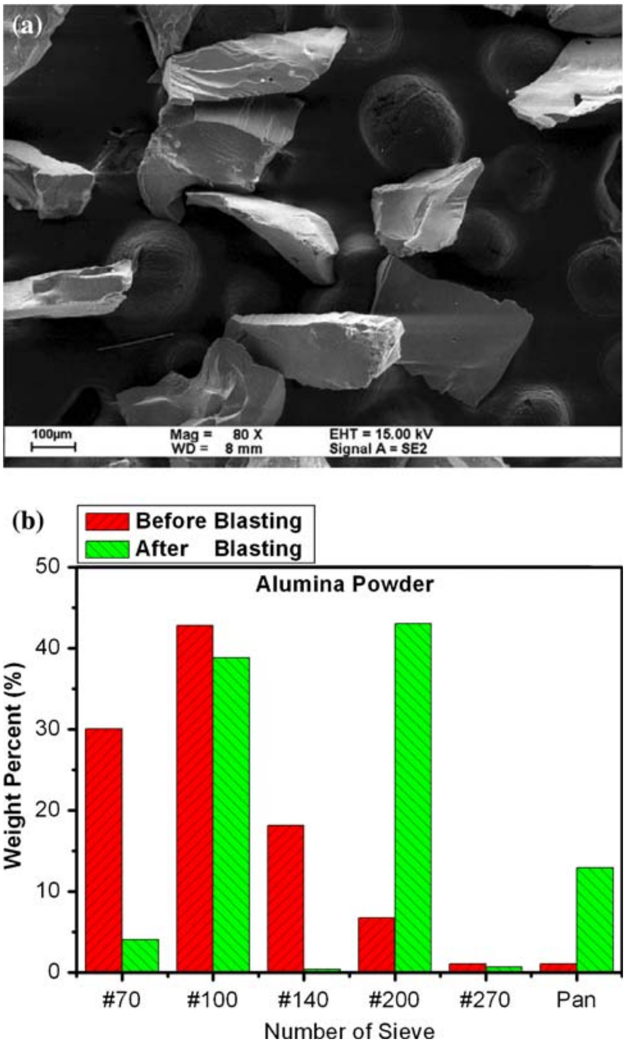


Fig. 2 (**a**) Morphology of the alumina powders; (**b**) sieve analyses before and after blasting treatment

Results and discussion

Effect of blasting conditions on the glossiness and L* of the samples

When iron and alumina powders were used to blast the 5052 alloy, increasing the blasting pressure (1–4.5 kg/cm^2) increased the root mean square roughness (Rq) from 3 to 6 μm and from 2 to 4 μm. When iron and alumina powders were used to blast the 1050 alloy, the root mean square roughness scattered from 4.2 to 8.5 μm and 3.5 to 6.8 μm, For a given blasting pressure, using iron powders yielded a rougher surface than did using alumina powders, due to differences in the density which generated varying impact momentums during blasting. In addition, the blasted 1050 alloy possessed higher root mean square roughness values than the blasted 5052 alloy, since the latter alloy takes advantage of high strength to resist deformation; yield strength Al5052-H32 alloy (195 MPa) and Al1050-H16 alloy (124 MPa).

Figure 3 shows the relations of the measured glossiness versus root mean square roughness of the 1050 and 5052 alloys after blasting. The relation of glossiness versus root mean square roughness of the two samples after blasting with iron powders was similar; only the relation curve shifted leftward when the 5052 alloy was blasted by alumina powders.

After blasting, the powders were collected and removed for sieve analyses as shown in Figs. 1b and 2b. The Al5052-H32 substrate is harder than the Al1050-H16 alloy and the alumina is fragile. During blasting, most alumina powders experience significant fracturing, yielding an increase in the amount of fine particles, especially when treating the 5052 alloy. The sieve analyses of the iron powders (with and without blasting) showed a minor variation, mainly due to wear. The leftward shift of the curve is mainly due to an increase in the amount of fine powder when the 5052 was blasted by alumina.

Glossiness is the relative luminous reflectance of a specimen's surface in the mirror direction [11]. The light reflected from the sample's surface becomes much more scattered as the surface gets rougher [12]. Surface roughness can be imagined as the sum of an infinite number of

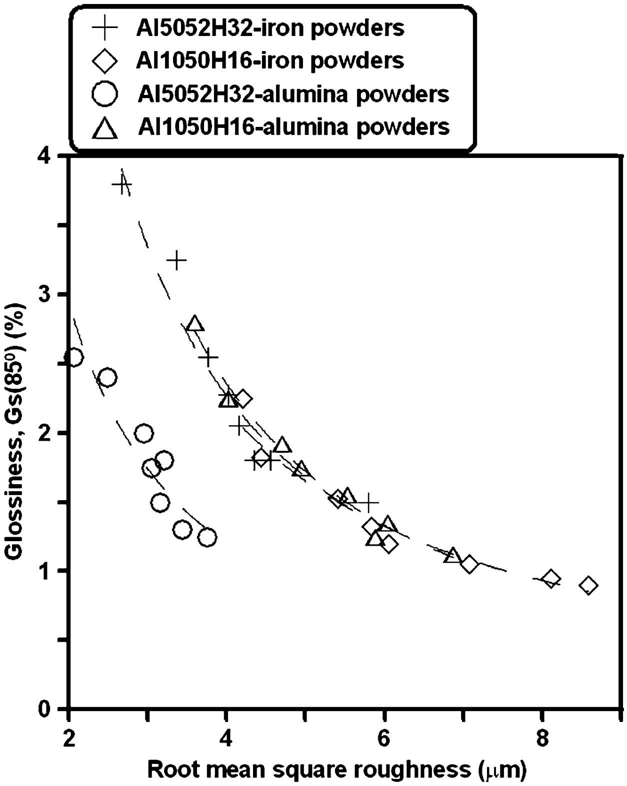


Fig. 3 Relation of measured glossiness Gs(85°) versus root mean square roughness (Rq) for the blasted Al1050-H16 and Al5052-H32 alloys

sinusoidally varying concavities on a surface, all with different spatial frequencies. The higher the spatial frequencies, the greater the amount of light scattered [13]. Glossiness increases as the surface becomes smoother. The measured glossiness (Gs(85°)) decreased as the root mean square roughness increased from 2 to 8 µm; see Fig. 3. For a given root mean square roughness, blasting of the 5052 alloy with iron powders yielded a higher glossiness than did blasting with alumina, mainly due to difference in the cavities on the blasted surface. Figure 4a, b shows SEM observations of the blasted surfaces of the 1050 alloy blasted with alumina and iron powder, respectively. The sample's surface blasted with iron powders had smooth concave cavities, while that blasted with alumina had long wedge-type cavities.

The measured lightness versus the root mean square roughness of the two samples (5052 and 1050 alloy) is shown in Fig. 5a. The lightness (L*) increased as the root mean square roughness increased after being blasted with iron powders. However, the lightness of the 5052 alloy sample decreased as the root mean square roughness increased after blasting with alumina powders. To find reasons for this difference, we used two sizes of alumina powders (#80 and #120) to blast 1050 alloy samples.

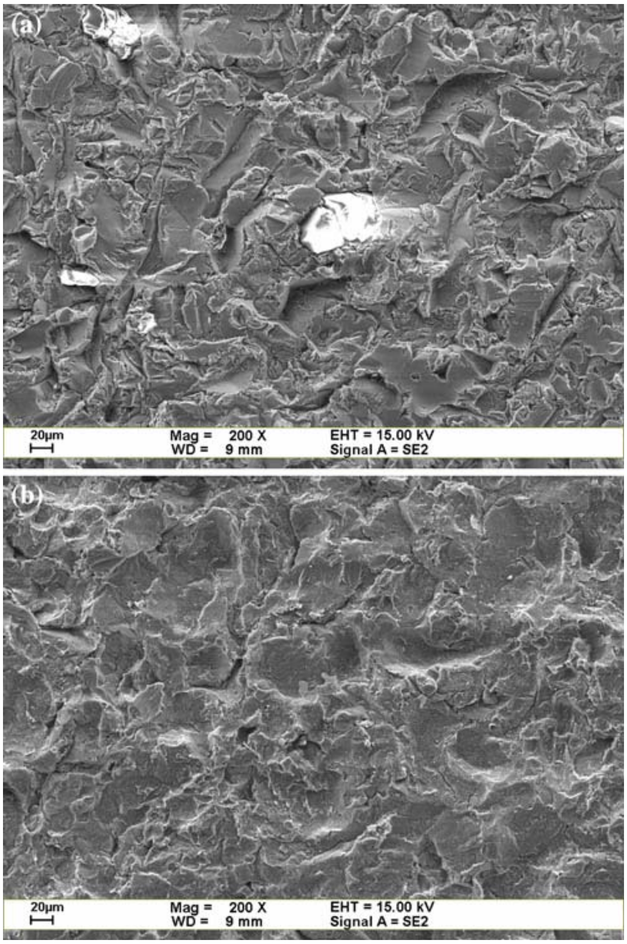


Fig. 4 SEM observations of the blasted surfaces of the 1050 alloy blasted with (**a**) alumina and (**b**) iron powder

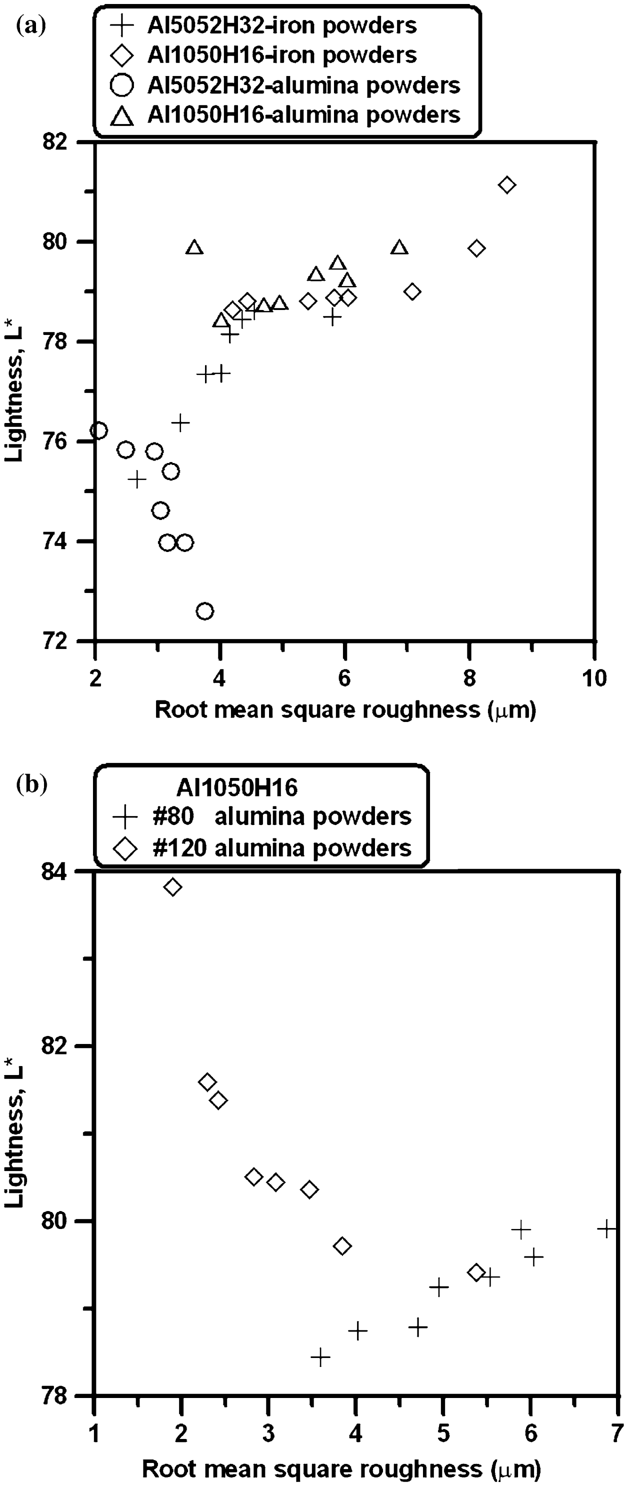


Fig. 5 Relation of measured lightness (L*) versus root mean roughness (Rq) for (**a**) Al1050-H16 and Al5052-H32 alloy samples blasted with iron and alumina powders (grit #80); (**b**) 1050 alloy blasted with #80 and #120 alumina powders

Figure 5b shows if a finer alumina powder was used, the root mean square roughness increased and the lightness decreased. Therefore, it can be seen that the decrease of lightness following the increase of the root mean square roughness is mainly due to the effect of the fine alumina powders, which decrease the fraction of wedge-type cavities.

Effects of abrasives on reflectance after sequential surface treatment

After blasting, 1050 and 5052 alloy samples were sequentially alkaline-etched, chemically polished, and anodized. The samples were controlled to have a fixed glossiness of Gs(85°) 2.0–2.2 after blasting. Figure 6a, b shows the measured reflectance of 1050 alloys blasted with alumina and iron powders, respectively. The measured glossiness and L*a*b* values are also included for comparison.

Using iron powders can make the blasted 1050 alloy surface more yellowish but slightly darker than using alumina powders; a L* value of 77.9 versus 79.1; a b* value of 3.39 versus 0.96. This is probably due to the effect of debris from the iron and alumina powders becoming embedded in the blasted surface; see also Fig. 4a, b. The glossiness remained the same (Fig. 6b) or slightly decreased after alkaline etching (Fig. 6a), but the reflectance was significantly increased. This was found to be the case for 1050 alloy samples after blasting with either alumina or iron powders. The L* values increased from 79.1 to 90.7, and from 77.9 to 93.2, for the 1050 alloy blasted with alumina and iron powders, respectively. Alkaline etching was more effective for the 1050 alloy when blasted with iron abrasives than when blasted with alumina, due to the effects of debris embedded in the blasted surface. Iron debris enhances the surface etching.

Chemical polishing further increased the reflectance and glossiness of both samples; using iron powder produced a more remarkable to rise in glossiness than could be obtain using alumina powders; Gs(60°) 30.1 versus 15.6. After chemical polishing, the surface's topography changed to become smoother; the micro-cavities were further polished to reveal a shining metal surface. The measured reflectance was actually close to that of pure Al [14]. The glossiness of samples blasted with alumina and iron powders after chemical polishing were 15.6 and 30.1, respectively. Iron powders could be used to obtain a higher glossiness, mainly due to more effective etching during chemical polishing. The glossiness was increased, because the roughened surface was smoothed by chemical polishing.

After the anodizing treatment, the glossiness of the 1050 alloy blasted with alumina decreased from 15.6 to 5.6 and

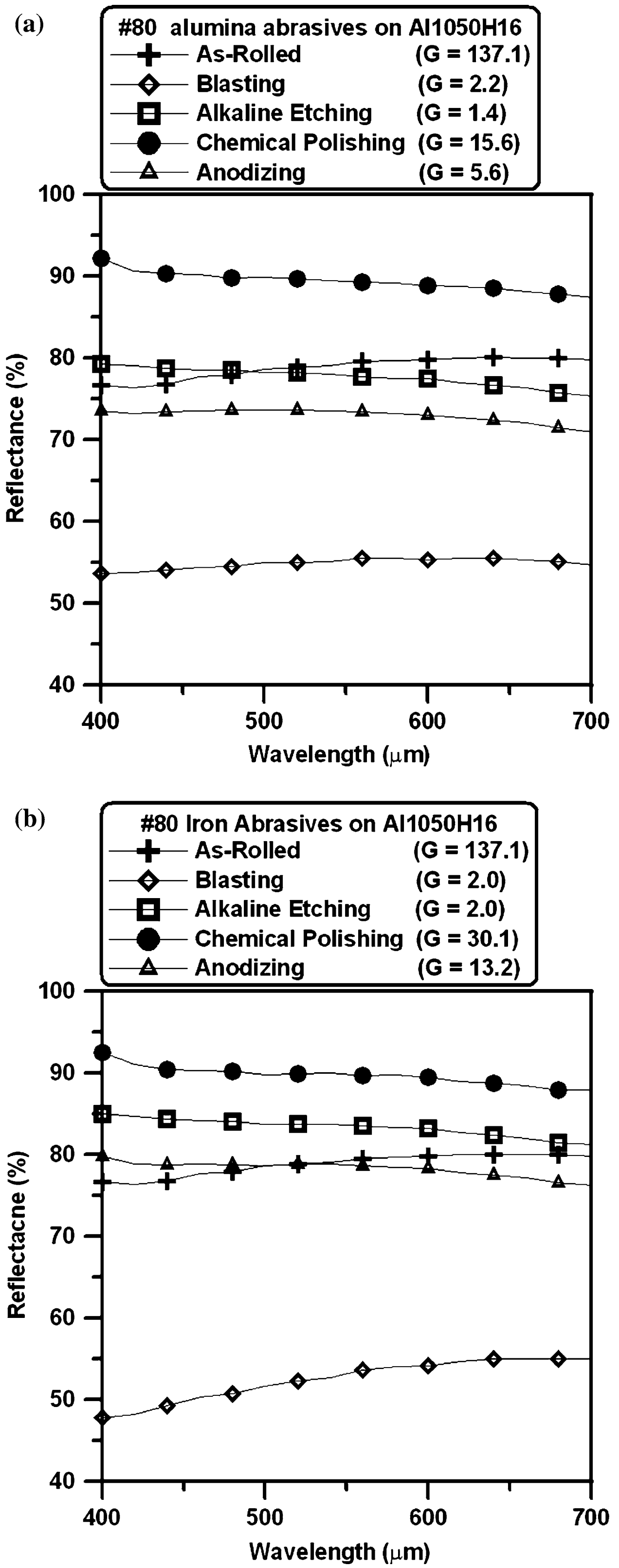


Fig. 6 Measured reflectance of the Al1050-H16 alloy, including the as-receiving alloy, after sequential alkaline etching, chemical polishing, and anodizing; samples were blasted with (**a**) alumina powders and (**b**) iron powders

it decreased from 30.1 to 13.2 if blasted with iron powders. The anodic film that grew on the 1050 alloy was about 10 and 8 μm in thickness, after blasting with alumina and iron powders, respectively. Blasting with iron powders can produce a high degree of plastic deformation and increase amounts of dislocation, which affect the movement of ions and the growth rate of the anodic aluminum oxide film. The anodic film did not change the surface's topography, but it did affect the reflectivity of light impinging on the surface, thereby decreasing measured reflectance, the L* value decreased from 95.7 to 88.6 (after blasting with alumina) and from 95.9 to 91.0 (after blasting with iron powder) as shown in Fig. 6a, b. The latter sample possessed higher "L*" values, mainly due to a thinner film thickness. The transparency of the anodic film led the reflectance curves to retain almost the same pattern before and after the anodizing treatment. Apparently, difference in the pre-treatment significantly changed the glossiness and "L*" values for both 1050 and 5052 alloy.

Figure 7a, b shows the measured reflectance of the 5052 as-receiving alloy after different pre-treatments and the anodizing treatment. The as-receiving samples of 5052 alloy possessed a lower reflectance, especially in the short wavelength zone than did the 1050 alloy, although the glossiness of 5052 alloy was higher, Gs(20°) 146 versus 137. The L*a*b* value for the as-receiving 1050 and 5052 sheet metal were (91.3, 0, 1.52) and (86.1, 0.44, 4.49), respectively. The latter alloy contains about 2.2–2.8 mass% Mg which was reflected by the sample's surface being more colorful, in particular yellowish.

After pretreatment, the progressive development of the reflectance curve of the 5052 alloy followed the same pattern as that at the 1050 alloy; compare Figs. 7a, b and 6a, b. For a given pretreatment, the 5052 alloy showed a relatively lower reflectivity than did the 1050 alloy, mainly due to former material containing Mg. After chemical polishing, the measured glossiness values shown when the 5052 alloy samples were concerned yield greater glossiness, Gs(60°) 40 and 17.9 for using iron and alumina blasting powders, respectively, than when the 1050 alloy samples were treated, Gs(60°) 30.1 and 15.7. This difference can be attributed to the birth of soluble Mg and/or intermetallic compound associated with the embedded iron debris which enhances etching [15, 16]. These factors make the 5052 alloy more reactive during chemical polishing; especially blasted with iron powders.

After anodizing treatment, the anodic film on the surface of 5052 alloy blasted with alumina and iron powders grew about 11 and 10 μm. The high deformation of the surface was accompanied by high residual stress, so a thinner anodic film developed as in case of treating the 1050 alloy. In addition, the anodic film on the 5052 alloy, possibly composed of imperfection originating from Al–Mg and/or

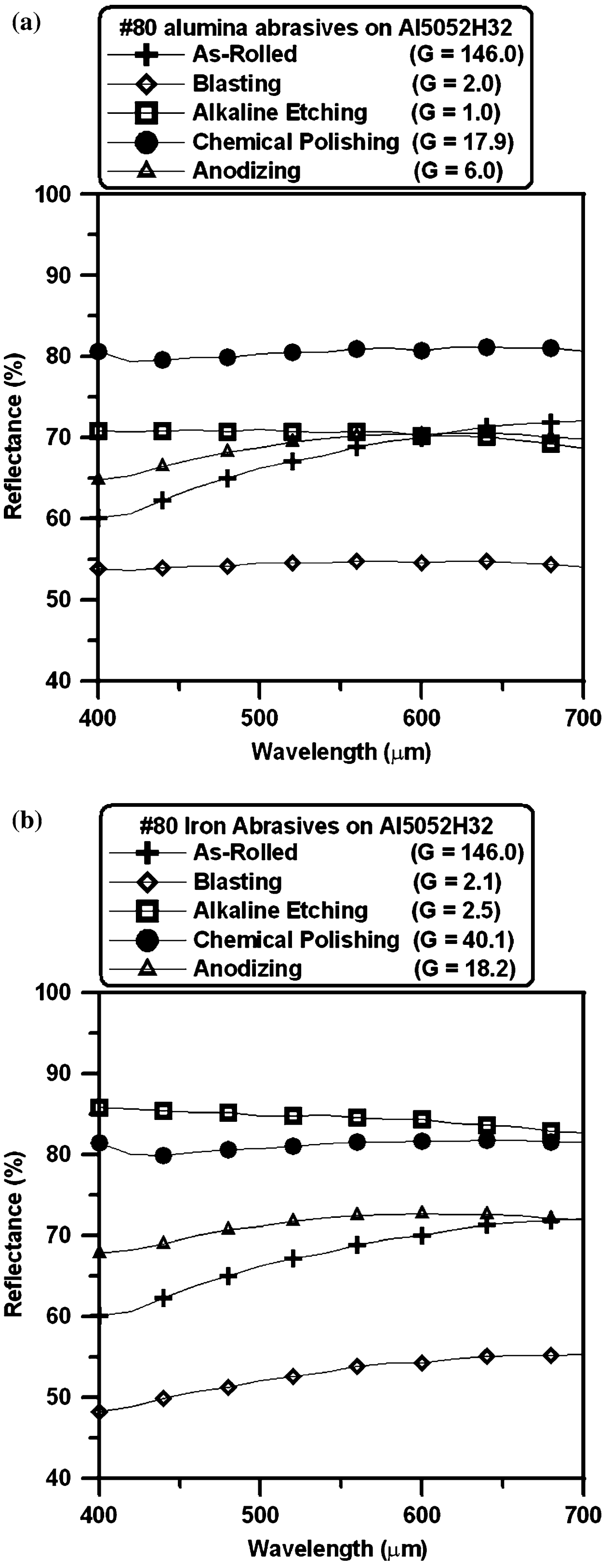
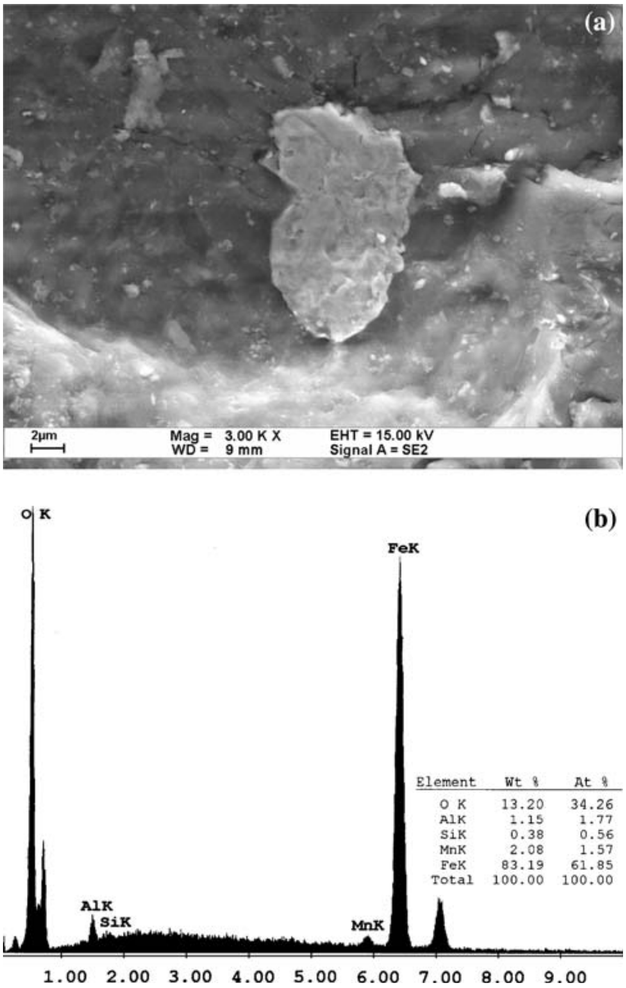


Fig. 7 Measured reflectance of the Al5052-H32 alloy, including the as-receiving alloy, after sequential alkaline etching, chemical polishing, and anodizing; samples were blasted with (**a**) alumina powders and (**b**) iron powders

Al–Mg–Fe, caused the transparence of the film to be deteriorated [15]. The reflectance of the 5052 alloy decreased and was much more yellowish in color than that of the 1050 alloy. The shorter wavelength of the light was partly absorbed or scattered by the anodic film on the 5052 alloy (comparing Figs. 6 and 7) was due to effect of Mg and/or intermetallic compounds in the matrix [15, 16].

To sum up, the glossiness of samples blasted with iron powders was higher than that of those blasted with alumina powders after chemical polishing. During dissolution, the iron embedded on the surface (Fig. 8) and/or contained in the aluminum alloy is preferential for function it as a cathode, which can enhance the etching rate. The etching rates are indeed affected by the population of intermetallic particles, particularly $FeAl_3$, in the matrix of the aluminum alloy [17].

Magnesium up to 1.0 mass% is soluble in aluminum at RT [18]. The addition of magnesium decreases the corrosion resistance of the aluminum alloy and increases the dissolution rate during chemical polishing. This means that cavities in the alloy's surface can be polished more effectively during chemical polishing of the 5052 alloy.



Element	Wt %	At %
O K	13.20	34.26
AlK	1.15	1.77
SiK	0.38	0.56
MnK	2.08	1.57
FeK	83.19	61.85
Total	100.00	100.00

Fig. 8 (**a**) SEM observation of the 1050 alloy sample blasted with iron powder; (**b**) EDX analysis of the embedded debris

Surface observations

Figure 4a, b shows the surface morphologies of the 1050 alloy after being blasted with alumina and iron powders, respectively. After being blasted with alumina powder, the sample surface shows wedge-type cavities with sharp corners while being blasted with iron powder shows smooth concave cavities. Fine alumina debris was embedded in the blasted surface as confirmed by EDAX analyses; see Fig. 4a. A piece of iron debris trapped on the blasted surface is shown in Fig. 8.

The residual stress within the colony of depressed cavities is determined solely by the depth of yielding during shot-peening [19]. The deformed cavity produced varying residual stress. Smooth concave cavities (Fig. 8, iron powder) possess less surface area than do wedge-type cavities with sharp corner (Fig. 4, alumina). For a given blasting pressure, using iron powders could yield greater impact energy than using alumina powders, leading to deeper indentations than did alumina powder. Alumina possesses a great stiffness but a low elongation. When powders impact on the metal surface, alumina powders tend to fracture while iron powders tend to wear. Thus for a given blasting pressure, the metal substrate exerted greater residual stress when iron powder was used as the blasting media than the alumina powders was used.

Conclusion

The glossiness of a blasted Al1050-H16 alloy decreased as the surface roughness increased. The surface was less roughened if the Al5052-H32 alloy was blasted with alumina powder than when it was blasted with iron powder. Using iron powder yielded smoother concave cavities, while using alumina yielded wedge-type cavities on the blasted surface. The different surface topographies associated with variations in the residual stress and embedded debris affected the glossiness and reflectance after subsequent chemical and electrochemical processes. Using iron powders raised the glossiness significantly after alkaline etching and chemical polishing. The formation of anodic coatings was affected by residual stress. Using iron powders yielded a higher degree of residual stress and a thinner anodic film. The reflectance was reduced by the formation of anodic coatings. The anodic coatings of the Al1050-H16 alloy were nearly transparent. A second phase trapped in the anodic film affected the cosmetic appearance at Al5052-H32. The reflectance of the anodized surface of the 5052 alloy sample was much more yellowish than was the 1050 alloy.

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