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Research Article

T4 and T6 Treatment of 6061 Al-15 Vol. % SiC_P Composite

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Aging temperature history has profound effect on the mechanical and corrosion behavior of 6061 Al/SiC composite. In order to understand the effect of aging on the corrosion resistance, the natural and artificial aging behavior of 15 vol. % 6061 Al-SiC_P composites was studied using the aging treatment and the Brinell hardness measurements. The aging curves for the composite (T6 treated) were determined at various aging temperatures such as room temperature, 140, 160, 180, 200, 220, and 240°C. According to the peak hardness variation with temperature profile, it is found that the composite is underaged at 140°C and 160°C. Peak aging takes place at 180°C. Overaging takes place at 200°C, 220°C, and 240°C. The natural aging characteristics of the composite (T4 treated) are also studied using the Brinell hardness measurements.

1. Introduction

Metal matrix composites (MMCs) are a broad family of materials aimed at achieving an enhanced combination of properties. The addition of a ceramic reinforcement phase in monolithic metal alloys significantly alters their mechanical and physical properties, as well as deformation behavior [1]. Particulate-reinforced metal matrix composites (PRMMCs) are one class of MMCs. They generally comprise a ductile metallic alloy reinforced with a hard ceramic reinforcing material in the form of particles with a variety of sizes and shapes [1, 2]. The composite material under consideration, which is cast 6061 aluminum alloy reinforced with 15 volume % of SiC particulates, is cited as 6061 Al/SiC/15_p. These metal matrix composites (MMCs) using aluminum alloy as the matrix such as 6061 Al with SiC particles reinforced in (6061 Al/SiC_P) have found vast applications in automotive, aerospace, marine, and other allied fields, which have aggressive environment [3]. The ultimate goal of an engineer is to design metal matrix composites (MMCs) to have good mechanical properties and inherent corrosion resistance [4]. The aging temperature history has an effect on the mechanical and corrosion behavior of the composite [5, 6]. Present work was initiated to study the natural (T4) and artificial (T6) aging response of the composite.

2. Experimental Work

In the present work, 6061 Al-15 volume percentage SiC composite material is under consideration. The composition of the base metal Al 6061 alloy is given in Table 1. The composite is made of 6061 Al alloy reinforced with particulate SiC (99.9% purity) and 23 μm size. It was prepared by stir casting technique. The composite in the form of cylinders was extruded. The extruded 6061 Al/SiC composite rods were cut into 2 cm × 2 cm × 1 cm dimensions for hardness measurement. All specimens are solution-treated at 558°C for 1 hour, water-quenched, and then aged at room temperature (T4 treatment), 140, 160, 180, 200, 220, and 240°C for various durations of time (T6 treatment). The age-hardening responses of the composite are characterized using the Brinell hardness measurements.

Figure 1 shows the micrograph of the as-received 6061 Al/SiC composite. Uniform distribution of the reinforcement is clearly visible. By Archimedes method and acid dissolution test, the uniformity in SiC particles distribution is ensured by determining the volume fraction of the reinforcement of the composite.

3. Results and Discussion

Table 2 gives the Brinell hardness values of natural aging, and Figure 2 shows the corresponding hardness profile.

Table 1: Standard composition of Al 6061 alloy.

Element	Cu	Si	Mg	Ti	Mn	Fe	Cr	Zn	Al	Others total
Composition (Wt. %)	0.15–0.40	0.40–0.80	0.80–1.20	0.15 max	0.15	0.70 max	0.04–0.35	0.25 max	Bal	0.15 max

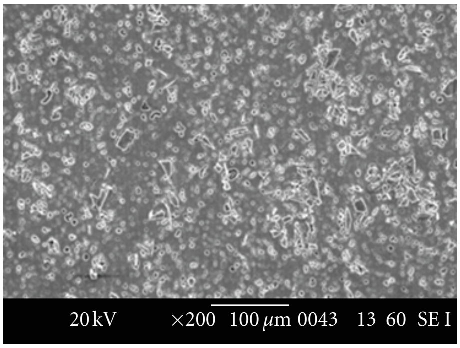

Figure 1: SEM micrograph of the 6061 Al/SiC composite.

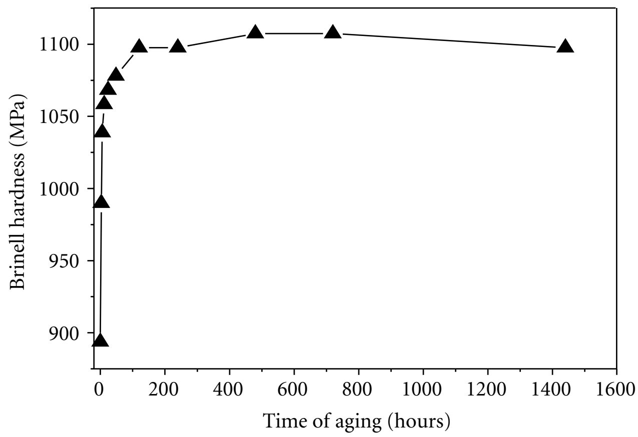

Figure 2: Hardness variation with time in T4 treatment.

Table 2: The Brinell hardness values of T4-treated 6061 Al-SiC composite.

Time of aging (hours)	Indentation diameter (mm)	Brinell hardness (kgf/mm^2)	Hardness (MPa)
0	3.67	91	893.7
3	3.49	101	989.8
6	3.41	106	1038.8
12	3.38	108	1058.4
24	3.37	109	1068.2
48	3.35	110	1078
120	3.32	112	1097.6
240	3.33	112	1097.6
480	3.31	113	1107.4
720	3.31	113	1107.4
1440	3.33	112	1097.6

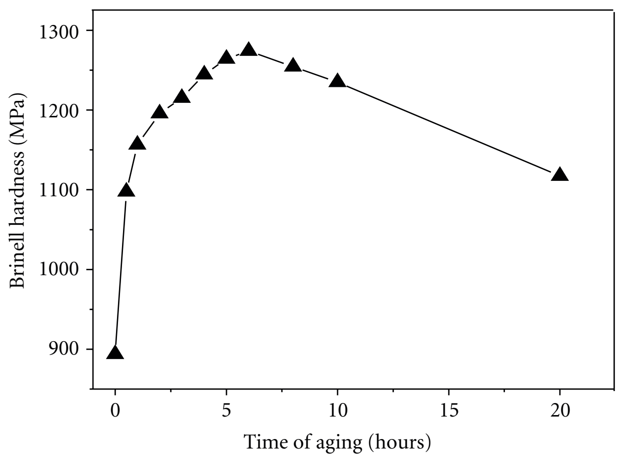

Figure 3: Hardness variation with time in T6 treatment at 140°C.

The hardness profile of natural ageing (T4 treatment) shows a sharp increase in hardness after the solution heat treatment for few hours. Then an exponential increase is observed up to 500 h. Peak hardness reaches after 500 h, and the hardness decreases gradually after 720 h of T4 treatment. The Brinell hardness values of T6 treated 6061 Al-SiC Composite at various temperatures are given by Table 3. Table 4 gives peak hardness values for various aging temperatures. Hardness variations with aging time in T6 treatment at various temperatures are given by Figures 3, 4, 5, 6, 7, and 8. Figure 9 gives the hardness variation with aging temperature and time in T6 treatment. Figure 10 gives the peak hardness variation with aging temperature in T6 treatment.

There are two ways to aid in the diffusion of the Mg and Si (which is paramount to forming the Mg_2Si precipitates): by heating the alloy and/or by allowing enough time to elapse. This process is called aging or age hardening or precipitation hardening. It may be done naturally (i.e., at room temperature) by providing enough time for the Mg

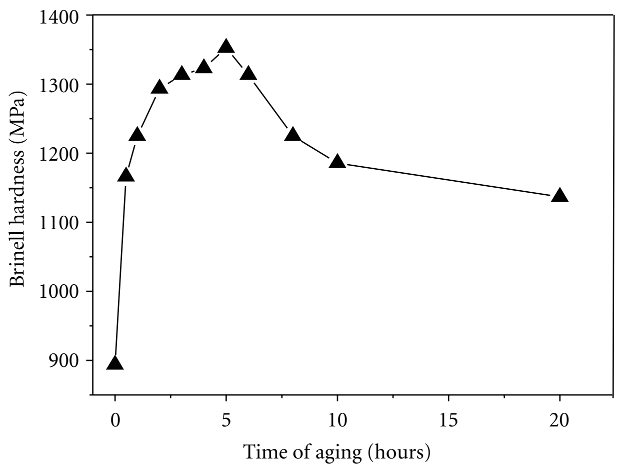

Figure 4: Hardness variation with time in T6 treatment at 160°C.

Table 3: The Brinell hardness values of T6-treated 6061 Al-SiC composite.

Time of aging (hours)	Brinell hardness (In MPa) of the composite aged at					
	140°C	160°C	180°C	200°C	220°C	240°C
0	893.7	893.7	893.7	893.7	893.7	893.7
0.5	1097.6	1166.2	1244.6	1234.8	1205.4	1195.6
1	1156.4	1225	1313.2	1332.8	1283.8	1254.4
2	1195.6	1293.6	1401.4	1372	1362.2*	1274*
3	1215.2	1313.2	1430.8	1401.4*	1332.8	1254.4
4	1244.6	1323	1450.4*	1342.6	1313.2	1244.6
5	1264.2	1352.4*	1401.4	1323	1283.8	1215.2
6	1274*	1313.2	1352.4	1264.2	1234.8	1195.6
8	1254.4	1225	1303.4	1205.4	1205.4	1185.8
10	1234.8	1185.8	1244.6	1185.8	1185.8	1176
20	1117.2	1136.8	1146.6	1127	1136.8	1127

* Peak hardness.

Table 4: Peak hardness variations with temperature.

Temperature (°C)	Brinell hardness (MPa)
140	1274
160	1352.4
180	1450.4
200	1401.4
220	1362.2
240	1274

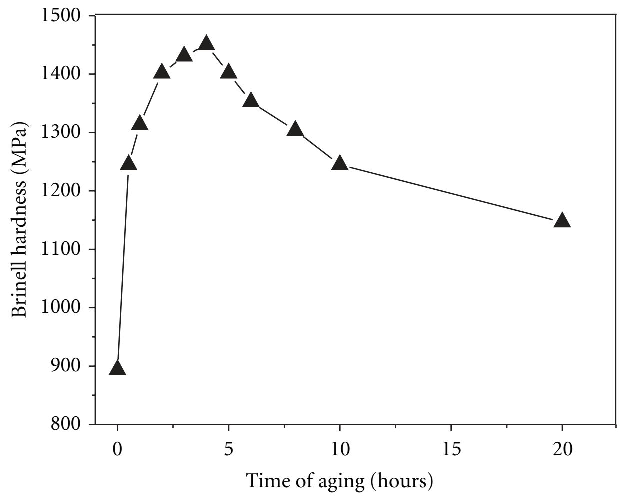

Figure 5: Hardness variation with time in T6 treatment at 180°C.

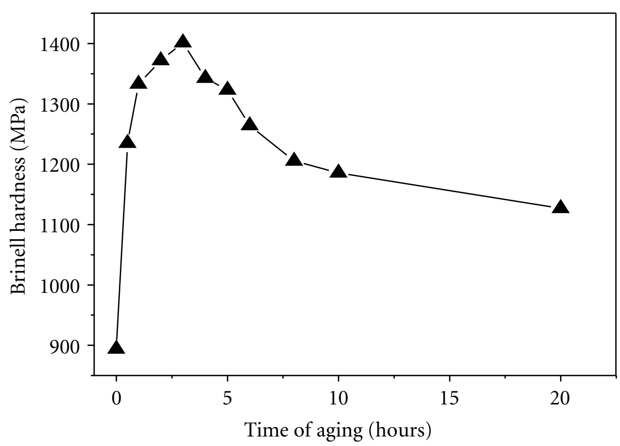

Figure 6: Hardness variation with time in T6 treatment at 200°C.

and Si to diffuse. However, since diffusion is hampered by lower temperature, it may take years for enough diffusion to form the Mg_2Si precipitates and adequately enhance the physical properties of the alloy. Because of this, the supersaturated solid solution may be taken to some intermediate temperature which is still in the $\alpha + Mg_2Si$ part of the phase diagram, in order to speed up the diffusion of the atomic species necessary to form the precipitate (in this case, Mg and Si will precipitate as Mg_2Si). This is called artificial aging and is the most common method of aging. For the 6061 Al-alloy composites the intermediate aging temperature is about 200°C: by holding several specimens for different times at this aging temperature, the effect of aging time on the mechanical properties of the material can be determined. The maximum hardness and strength develops when alloy is aged at a suitable temperature which ranges between 120°C and 200°C [7].

Spontaneous decomposition of supersaturated solid solution takes place during aging treatment. The higher the aging temperature and the higher the degree of supersaturation, the faster the aging [8].

The following steps are associated with the process of precipitation hardening in most of the aluminium alloy composites.

(i) The first stage preceding the formation of particles of the precipitating phase consists of rearrangement of atoms within the crystal lattice. This constitutes formation of clusters and Guinier-Preston zones. During this process mechanical properties are improved due to development of microstrains in the lattice.

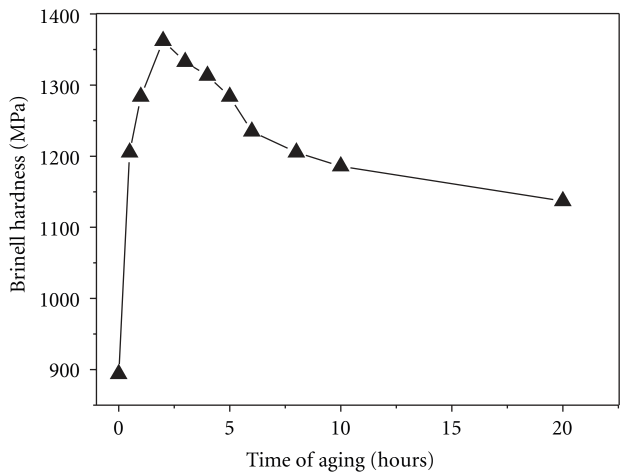

FIGURE 7: Hardness variation with time in T6 treatment at 220°C.

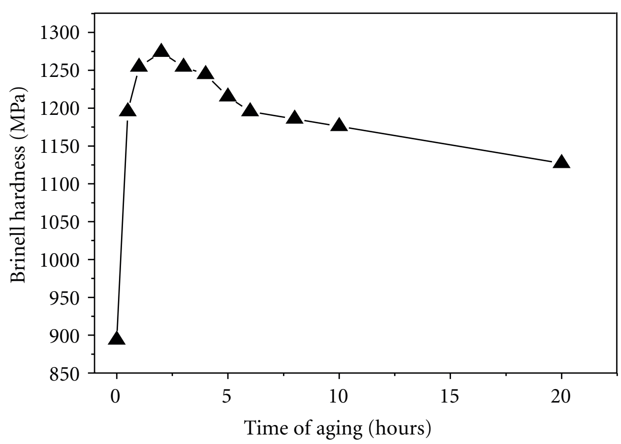

FIGURE 8: Hardness variation with time in T6 treatment at 240°C.

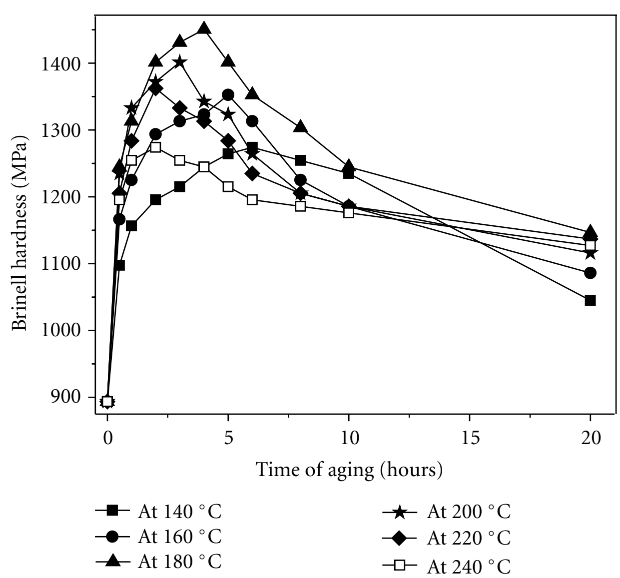

FIGURE 9: Hardness variation with time and temperature in T6 treatment.

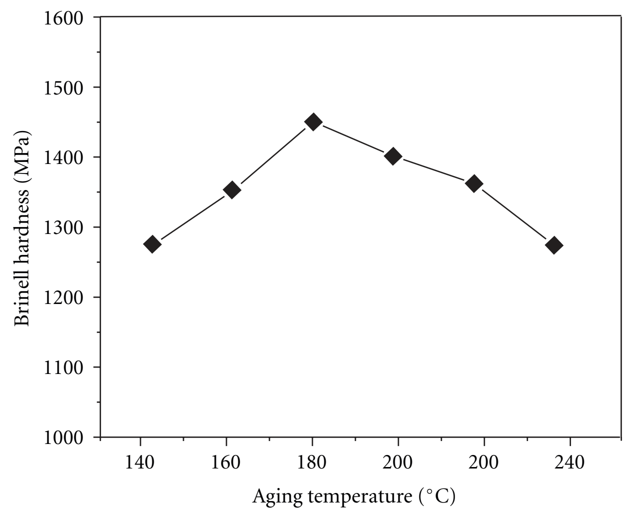

FIGURE 10: Peak hardness variation with temperature.

(ii) Formation of transition structures in the form of modified Guinier-Preston zones (e.g., GP II zones) and intermediate phases. This may give rise to maximum strengthening in the alloy.

(iii) Formation of stable phase from transition phases whose particles have common boundaries within the grains of the matrix.

(iv) Growth of certain larger particles at the expense of neighbouring smaller particles. Due to this, stress relief takes place in the lattice usually at higher ageing temperatures, which causes considerable decrease in strength and increase in ductility of the alloy [7].

The artificial aging is accelerated in the case of the composite owing to the presence of areas with a high concentration of dislocation close to the aluminum matrix-SiC reinforcement interface. On the contrary, dislocations do not affect the kinetics of natural aging; the driving force for this process only depends on the concentration of alloying elements in the supersaturated solid solution. The hardening during natural aging of the composite is due to the formation of primitive GP zones, while the artificial aging carried out basically causes the formation of the needle-shaped phase and the concomitant partial precipitation of the rod-shaped phase. The increase in hardness for the composite is possible if a full solution is reached [9].

The studies [7, 10] carried out by transmission electron microscopy, diffuse X-ray scattering, and resistometric measurements concur to indicate the following aging sequence for 6061 alloy and its composites: supersaturated solid solution → clusters of solute atoms and vacancies (primitive Guinier-Preston (GP) zones) → needle-shaped GP zones → rod-shaped, metastable, hexagonal, semicoherent β' phase → stable, incoherent, cubic, Mg_2Si precipitate (β phase). According to the A1-Mg-Si phase diagram melting of ternary eutectic Mg_2Si-(Al)-(Mg) phase takes place at 558°C. It is reported that the samples of 6061 Al/SiC composite, with the solution heat-treated at 558°C, exhibit better strength compared to the samples solution treated at 530°C after aging treatment [10].

According to the literature of the aging sequence of both 6061 alloy and composites [10], the variation of the hardness versus aging temperature and time can be correlated to the phase transformations taking place during aging treatment given to the composite. GP zone formation begins at room temperature and is fully realized under 200°C. Zone formation is a complex phenomenon: almost immediately after quenching clusters of silicon atoms and vacancies appear, and then magnesium atoms precipitate on nuclei [11]; these nuclei grow until formation of a needle-shaped phase with growth axis (major axis) lined up on the ⟨100⟩ matrix direction and ranging in length between 20 and 100 nm. Such zones are coherent with the matrix lattice in the (100) direction and progressively evolve toward a more ordered state. Above 200°C, GP zones are transformed into rod-shaped β' phase which is semicoherent with the matrix [11].

In natural aging treatment (T4), the peak hardness (1107.4 MPa) is achieved after 500 hours. Beyond 500 hours of aging the hardness remains constant. In artificial aging treatment (T6), as the temperature of aging increases, the time taken to reach peak hardness decreases. This is clearly visible from Figure 9. The peak hardness for artificial aging (1450.4 MPa) is achieved after 4 hours at 180°C. Based on the harness profiles the aged specimens are categorized into three groups namely (1) under aged (2) peak aged and (3) over aged. The variation in hardness with respect to time and temperature of aging can be correlated to the aging kinetics which results in variation of shape, size and distribution of precipitates in the matrix [12].

4. Conclusion

Results of T4 treatment of 6061 Al 15-Vol. % SiC_P composite show that the peak hardness is reached after 500 hours of aging at room temperature. The peak hardness is around 1097 Mpa. In T6 treatment, the composite is under aged at 140°C and 160°C. Peak aging takes place at 180°C. Over aging takes place at 200°C, 220°C, and 240°C. Maximum peak hardness (~1450 MPa) is obtained for the composite aged at 180°C for four hours. As the aging temperature increases in T6 treatment, the time to reach peak hardness decreases.

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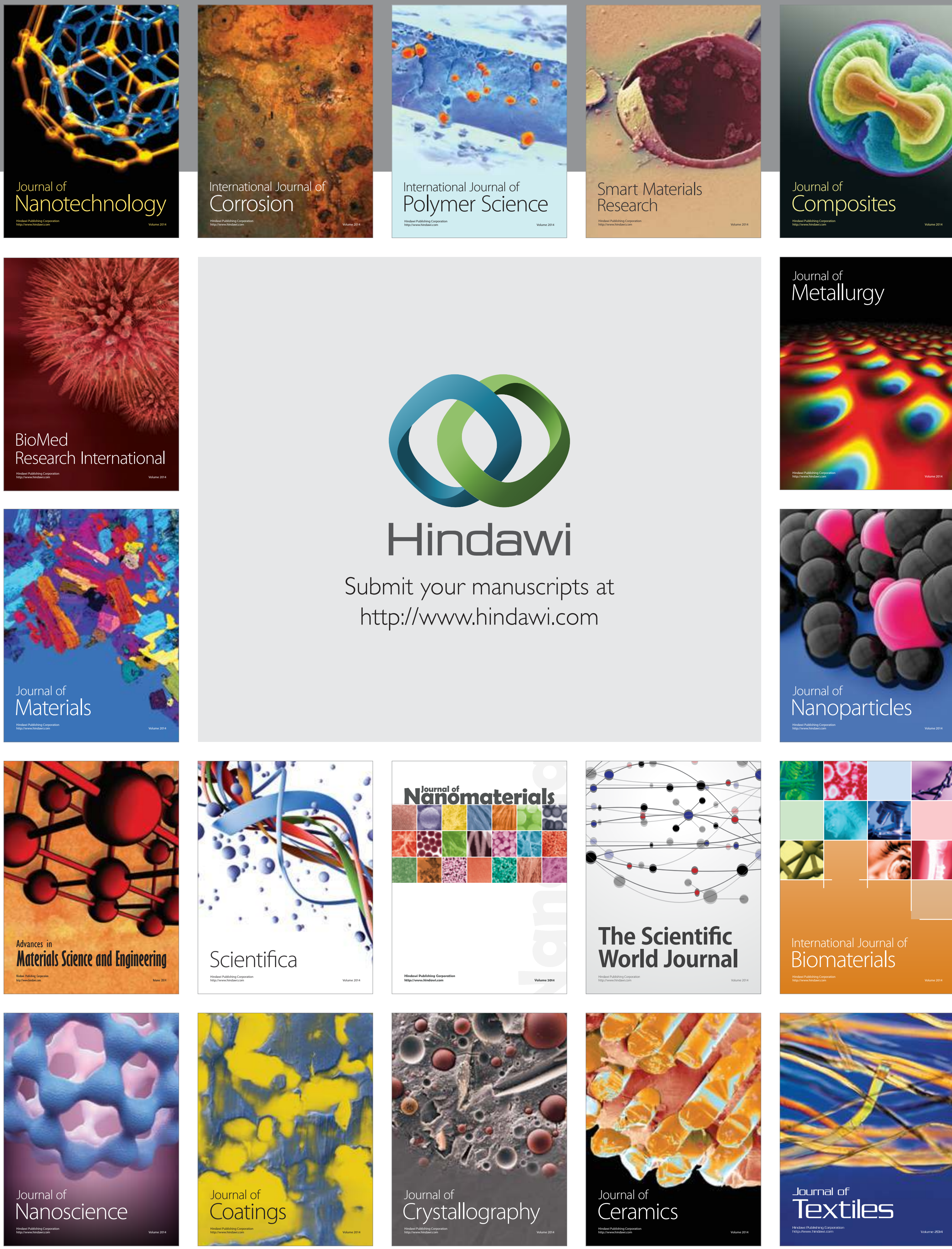

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