Effects of postcure temperature on mechanical properties of resin mineral composite for precision machine tool

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Abstract. Resin mineral composite has drawn much attention in the field of elementary machine components due to its excellent damping property. The effects of postcure temperature on mechanical properties of resin mineral composite were investigated in this paper. Research results showed that the glass-transition temperature of resin matrix, the surface hardness of resin matrix, the compressive strength of resin matrix, and the compressive strength of resin mineral composite increased with the increasing postcure temperature. If the postcure temperature increased from 30℃ to 120℃, the compressive strength of resin mineral composite increased by 17.34%, the compressive strength of resin matrix increased by 6.67%, the surface hardness of resin matrix in-creased by 54.16%, and the glass-transition temperature of resin matrix increased by 49.09%. The postcure process at 120℃ for 4 hours can be used to improve the me-chanical properties as a mature post-treatment technology for resin mineral composite. Good correlations were obtained between glass-transition temperature of resin matrix and surface hardness of resin matrix, compressive strength of resin matrix, and compressive strength of resin mineral composite. The correlations showed that the glass-transition temperature of resin matrix can be used to define and monitor the mechanical properties of resin mineral composite.

Introduction

With the development of precision and ultra-precision machining technologies, vibration generated during the machining process is now a key factor that impacts the dimensional precision and surface quality of work piece. How to minimize the vibration has become a more important issue for precision machine tool industry than before[1]. Resin mineral composite (RMC), also known as polymer concrete, is commonly composed of resin matrix, aggregates and filler. Excellent properties of RMC such as lower weight[2] and lower curing shrinkage[3] than ordinary Poland cement concretes, excellent damping property[1], good adhesion to other materials[4], and good corrosion resistance to chemical environment[5] have made it a very attractive material in various fields such as construction industry[6, 7], structural engineering[8, 9] and precision machine tools[10, 11], etc. In the field of precision machine tools, RMC has drawn special attention due to the excellent damping property. However, the low mechanical strength have restricted its widely application.

Previous studies show that the mechanical of RMC are highly affected by the constituents, such as resin dosage[11], fly ash[11, 12], types of the aggregates[11], mass content of aggregate[13], glass fiber[2, 14, 15], carbon fiber[14, 16] and types of resin[17], etc. Previous studies also show that the glass-transition temperature (T_g) is a very important factor to resin materials, those who can experience the glass transition during their service lifetime[18]. Postcure process on resin materials has been studied by many researchers. Rauhut,H,W[19, 20], studied the performance of postcure and nopostcure resin materials. Vo, Tien[21] studied the postcure temperature on hygro-thermal-mechanical properties of an out-of-autoclave polymer composite. R.J.C.CARBAS[22] studied the effect of cure temperature on T_g and mechanical properties of epoxy adhesives, finding that T_g, strength and stiffness vary as a function of the cure temperature of the epoxy adhesive. When cured below the $T_{g\infty}$, the T_g, strength and stiffness increased as the cure temperature increased. But there is no study that focused on the influence of postcure temperature on RMC.

In this paper, the effects of postcure temperature on T_g of resin matrix, surface hardness of resin matrix, compressive strength of resin matrix, and compressive strength of RMC were firstly investigated. Then the relationship between T_g and surface hardness of resin matrix, compressive strength of resin matrix, and compressive strength of RMC were also thoroughly investigated.

Materials

Aggregate. The aggregates used in this study were granite particles crushed from Jinan black, produced in Jinan, China. The aggregates were classified into five different groups according to the diameter of particles. The den-sity of the aggregates is 3.080g/cm3, the elasticity mod-ulus is 1.21~1.28GPa, and the compressive and flexur-al strength are 196MPa and 36.39MPa, respectively. The CLE of aggregates was about 5ppm/℃, when the test temperature ranged from 20 to 100℃.

Resin matrix. The resin used in this study is epoxy resin 618A, and the hardener is diethylenetriamine(DETA). Acetone was used to lower the viscosity of resin as diluents. The CLE of resin matrix without postcure process was about 90ppm/℃, when the test temperature ranged from 20 to 100℃. The density of resin matrix without post-cure process was 1.2g/cm3.

Filler. Fly ash was used as the additive, which is a by-product from burning coals in local power plants.

Preparation of testing samples

Casting process for RMC. Aggregates were dried for 6 hours at 105℃ to remove the moisture, and cooled at room temperature. The resin and hardener were mixed uniformly at a mass ratio 4:1 for 2 minutes, and mixed for another 2 minutes after the fly ash was added in. Then the aggregates, the resin matrix, and the filler were mixed together for another 8 minutes, and poured into the mould. The mould with mixture was fixed on a vibration table. The vibration frequency was 45Hz and the amplitude was 0.25mm. The mould vibrated for 20 minutes, then was put into a thermotank at 30℃ for 1 day. After removal from mould, the RMC was ready for the following experiments.

Casting process for resin matrix. The resin matrix was composed of epoxy resin and DETA. The mixture was mixed uniformly at a mass ratio 4:1 for 2 minutes, and then was poured into the mould. The mould with mixture in was put into a thermotank at 30℃ for a 1 day. After removal from mould, the resin matrix was ready for the following experiments.

Postcure process. The specimens were postcured at different temperature for 4 hours in a thermotank. The scheme of this process is outlined in Table 1.

Table 1. Postcure temperature and time

Postcure Temperature(℃)	30	40	50	60	70	80	90	100	110	120
Postcure Time(h)	4	4	4	4	4	4	4	4	4	4

Experimental testing

Compressive strength test of RMC and resin matrix. The compressive strength of RMC and resin ma-trix was obtained using a YE-2000 hydraulic pressure test machine. The size of RMC specimen was 40mm*40mm*40mm. The height and diameter of resin matrix specimen were 20mm and 10mm, respectively. There were five specimens for each cure temperature. The measurement temperature was 20℃.

Surface hardness test of resin matrix. The surface hardness of resin matrix was obtained using a MH-6 micro-hardness tester. Five specimens of 15mm*15mm*5mm for each cure temperature were machined and polished from resin matrix. The meas-urement temperature was 20℃.

Glass-transition temperature test of resin matrix. The glass-transition temperature of resin matrix was obtained using a PYC high temperature horizontal thermal dilatometer. Five specimens of 10mm*10mm*50mm for each cure temperature were machined from resin matrix. And the range of meas-urement temperature was 20℃ to 100℃.

Results and discussions

Effects of postcure temperature on glass-transition temperature of resin matrix. The effects of postcure temperature on T_g of resin matrix were shown in Figure 1. The research results showed that the T_g of resin matrix increased with the increasing postcure temperature. The tendency of T_g increased obviously as the postcure temperature increased from 30℃ to 80℃. As T_g approached 82℃ along with the postcure temperature approached 100℃, the increasing of T_g terminated.

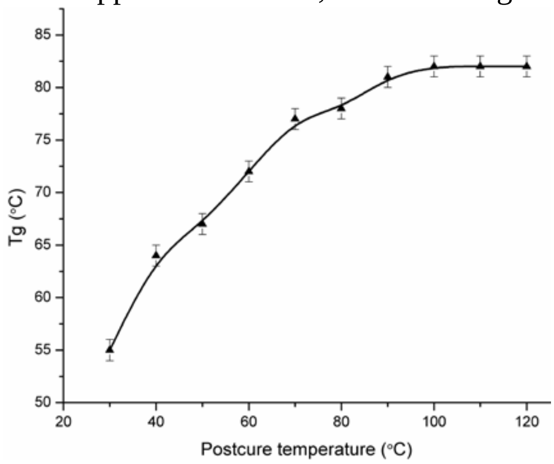

Figure 1. Effects of postcure temperature on glass-transition temperature of resin matrix

T_g is dominantly affected by curing temperature[23-25]. There is a significant dependence of the T_g on the molecular weight of the polymer. On increasing the molecular weight, M, the concentration of chain ends increases and the mobility averaged over all repeat units is enhanced, resulting in an increase in T_g[26]. DETA reacts rapidly with epoxy groups at an early stage, and epoxy groups consume rapidly. When the reaction arrived at a certain time, the consumption of epoxy became slowly. The reaction degree of epoxy groups with DETA is only 65% during the first three weeks at room temperature, which is not conductive to form macromolecular chain.[27] Improving the reaction temperature is necessary to accelerate the reaction and improve the degree of cure[21].

It can also be concluded that the degree of cure (DOC) increases as the postcure temperature increases, according to DiBenedetto's study that T_g increases proportionally with DOC[28].

Effects of postcure temperature on surface hardness of resin matrix. The effects of postcure temperature on surface hardness and T_g of resin matrix were shown in Figure 2. The research results showed that the surface hardness of resin matrix increased with the increasing postcure temperature. The surface hardness increased obviously as the postcure temperature increased from 30 to 80℃. The increasing tendency of surface hardness almost terminated as the postcure temperature exceeded 80℃. The maximum value of surface hardness of resin matrix in this test was 18.33MPa when the postcure temperature was 120℃, increased by 48%. According to Figure 2, the surface hardness of resin matrix increased almost the same as the T_g of resin matrix as the postcure temperature increased.

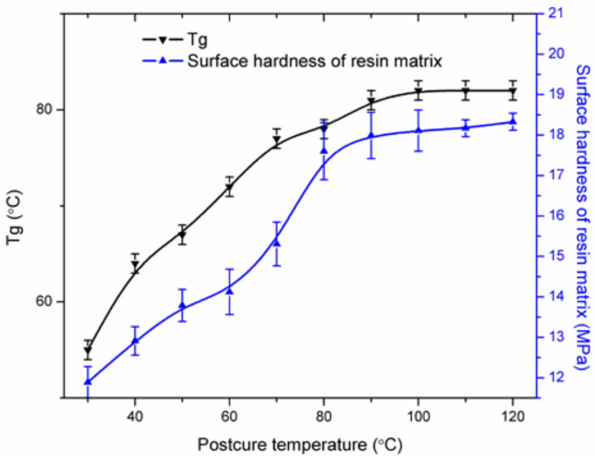

Figure 2. The effects of postcure temperature on surface hardness and T_g of resin matrix

As the postcure temperature increased, the crosslink density and molecular weight increased. Moderate crosslinking can effectively increase bonding between molecular chains, making slipping not easy to occur among the molecular chains, and increasing the strength. And when the molecular weight of polymer was low, the intensity of polymer would increase obviously as the molecular weight of polymer increased.

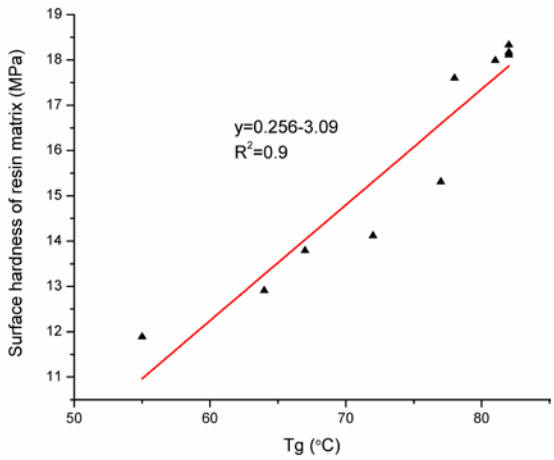

Figure 3. Linear relationship between T_g and surface hardness of resin matrix

To reveal the relationship between surface hardness of resin matrix and Tg, the surface hardness of resin matrix was plotted versus T_g in Figure 3. As Figure 3 illustrated that the surface hardness increased almost proportionally with Tg, and the adjusted R-Square is 0.9. The correlation between surface hardness of resin matrix and T_g of resin matrix can be used for monitoring and defining the curing condition and crosslink density of resin matrix.

Effects of postcure temperature on compressive strength of resin matrix and RMC. The effects of postcure temperature on compressive strength of resin matrix and RMC were shown in Figure 4 and Figure 5, respectively. The research results showed that the compressive strength of resin matrix and the compressive strength of RMC increased with the increasing postcure temperature. As shown in Figure 8, the tendency of compressive strength of resin matrix increased obviously as the postcure temperature increased from 30 to 100℃, and terminated as the postcure temperature approached 100℃. The maximum value of compressive strength of resin matrix in this test was 97.6MPa when the postcure temperature was 110℃, increased by 6.89%. As shown in Figure 9, for the postcure temperature ranging from 30℃ to 120℃, the compressive strength of RMC ranged from 141.19MPa to 165.67MPa, increased by 17.34%.

The crosslink density and molecular weight increased with the increasing of postcure temperature, resulting in the increasing of strength of polymer. This made the resin matrix a stronger network structure to bear and transmit stress. Then the stress inside RMC distributed more uniformly, avoiding RMC to be crushed due to the uneven internal stress.

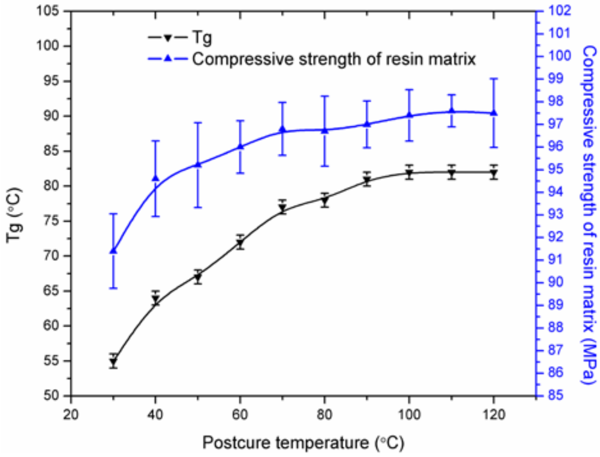

Figure 4. Effects of postcure temperature on compressive strength of resin matrix

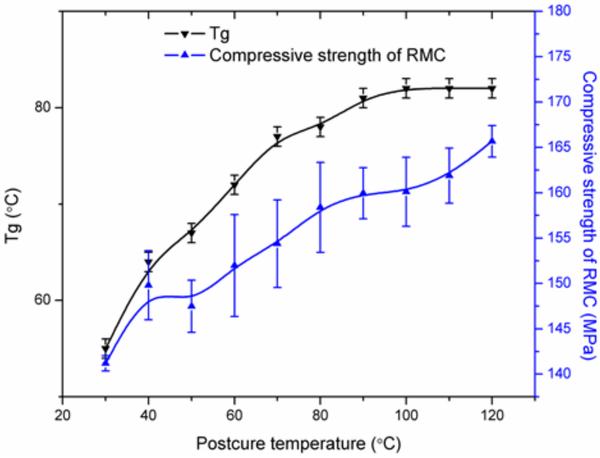

Figure 5. Effects of postcure temperature on compressive strength of RMC

The compressive strength of resin matrix and RMC were plotted versus T_g of resin matrix in Figure 6 and Figure 7, respectively. According to the obtained results, the compressive strength of resin matrix and RMC increased proportionally as the Tg of resin matrix increased, the adjusted R-Squares were 0.94 and 0.9, respectively. Good correlations were found between the T_g of resin matrix and the compressive strength of resin matrix and RMC. Because the T_g test of resin matrix is much simpler and easier than the compressive strength test of RMC, the correlation between compressive strength of RMC and T_g of resin matrix can be used for obtaining useful information about the mechanical properties of RMC. And the T_g of resin matrix can be used to monitor and define the mechanical properties of RMC.

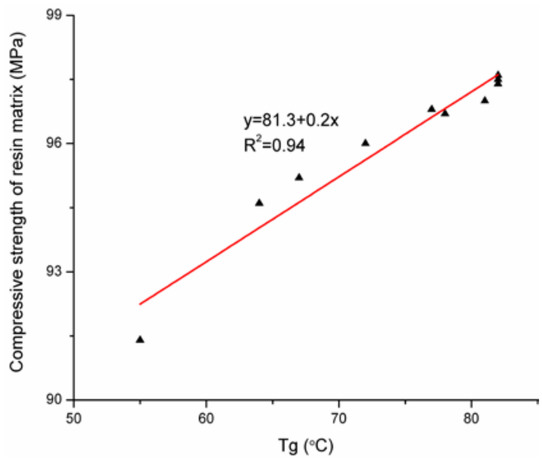

Figure 6. Linear relationship between Tg of resin matrix and compressive strength of resin matrix

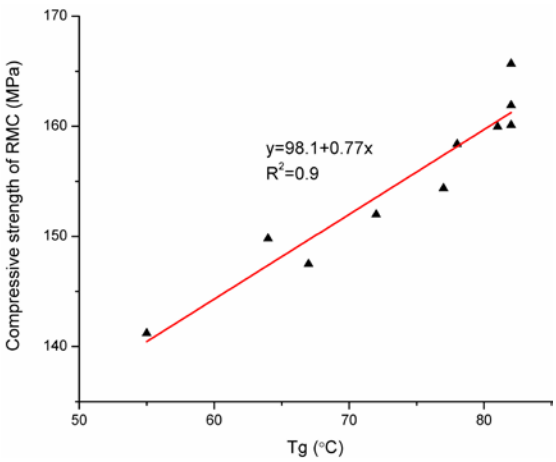

Figure 7. Linear relationship between Tg of resin matrix and compressive strength of RMC

Conclusions

Mechanical and thermal expansion properties of both RMC and resin matrix are strongly effected by postcure temperature. The following conclusion are drawn from the above experimental results and analyses.

1. The T_g of resin matrix increased as the postcure temperature increased. The maximum value of T_g is obtained as the postcure temperature exceed 90℃.
2. The compressive strength of RMC and resin matrix, surface hardness of resin matrix, increased as the postcure temperature increased. For postcure temperature ranging from 30 to 120℃， the compressive strength of RMC ranged from 141.19MPa to 165.67MPa, while the compressive strength of resin matrix ranged from 91.4 to 97.5MPa, and the surface hardness of resin matrix ranged from 11.89 to 18.33MPa.
3. The compressive strength of RMC and resin matrix, surface hardness of resin matrix, increased proportionally with the T_g.
4. As the T_g of resin matrix test is simpler and easier than the compressive strength test of RMC, the T_g of resin matrix can be used to obtain useful information for define and monitor the mechanical and thermal expansion properties of RMC. And the postcure process at 120℃ can be used to improve the mechanical and thermal expansion properties of RMC as a mature post-treatment technology.

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