The surface image and inner structure of electroless Ni-P-B₄C deposit layers were observed and analyzed by SEM, optical microscope and X-ray diffractometer. The results showed that with increase of the amount of B₄C particles in the plating solution, the number of the surface nodular protrusions increased. The particles of B₄C evenly dispersed on the Ni-P matrix and adhered well in the coatings. The presence of the B₄C particles does not change the phase composition. The mechanical properties of composite coatings were measured. The results indicated that with increase of the content of B₄C, the hardness and wear resistance were obviously improved, but the critical load was decreased.

It is well known that there are three types of material failure: corrosion, wear and fatigue. Wear is the main failure mode for many machine components. Improving surface hardness is one method to upgrade the wear resistance of materials. At present, to improve surface hardness and wear resistance, many treatment methods are adopted; for example, electroplating, carbon case hardening, nitrogen hardening, PVD, CVD, ion implantation, etc. Every technology has its limitations, however. Some have poor feasibility, and some are expensive. Electroless Ni-P composite plating is one of the new technical metal surface treatments. It offers excellent technical feasibility (good throwing power, uniform coating thickness, good surface smoothness, etc.), as well as other functional properties.

Many reports have been published worldwide that are mainly focused on electroless Ni-P composite plating. Although there are a few reports concerning Ni-P-B₄C deposits, little data was given. In this paper, the authors emphasize study of the structure and mechanical properties of Ni-P-B₄C deposit coatings.

Experimental Procedure
Electroless Composite Plating Solution
In the plating solution, sodium butanate and amino acetic acid are used as complexing agents, with sodium hypophosphite as reducing agent. Solution pH, 4.5 to 5.0, temp 85 °C. The particle size of the B₄C is W5. Mechanical agitation is employed at the rate of 750 rpm.

Pre-cleaned Substrates of Gray Cast Iron
The preparation and plating sequence for the substrates was chemical de-oiling and rust removal -> washing with deionized water -> chemical activation (15% H₂SO₄ solution), 25 °C , 8 sec) -> pre-plating Ni -> electroless plating.

Assessment of Coatings
The surface images before and after the wear test were observed by SEM, and the phase was analyzed by X-ray diffractometer. A scratch test was adopted to measure the adhesive force. The critical load, Lc, which first causes stripping during the scratch test is regarded as the adhesive force. Hardness was measured by a micro-hardness tester. The thickness of the deposit was 25 µm, and the load was 1 N. The wear test was conducted on a wear tester. The top sample was measured with sample rotation rate of 200 rpm; the bottom sample was compared, having rotated at 180 rpm. The wearability was expressed by the loss of weight of the sample before and after the test.

Results & Discussion
Surface Image & Inner Structure
Figures 1(a)(b)(c) are SEM micrographs of Ni-P, Ni-P-19%B₄C, and Ni-P-32%B₄C composite coatings, respectively. It can be seen from the figures that there are a few nodular protrusions and pores in the surface of the Ni-P deposit; more in the surface of the Ni-P-19%B₄C coating, but the surface of the Ni-P-32%B₄C deposit is almost covered with nodular protrusions. The micrographs indicate that, with increase of the content of B₄C particles, the surface nodular protrusions increase, but their size gets smaller. In addition, they show that the B₄C particles are partly exposed or wholly embed-
Mechanical Properties

Hardness

The hardness test of electroless Ni-P-SiC composite coatings indicated that the hardness depends on the hardness of the Ni-P matrix and the content of SiC. Accordingly, we first examined the relationship between the hardness of the Ni-P deposit coatings and the content of SiC. The results indicated that the greatest hardness of the Ni-P deposit coatings is HV 912 after one hr heat treatment at 350 °C.

Figure 4 shows the relationship between B₄C content and the hardness of Ni-P-B₄C at one hr heat treatment at 350 °C. The results show that the hardness increased considerably when the coatings contained B₄C particles, but the test data have some scattering, which may be because the load is so small that the indentation can only impinge partially on B₄C particle, or wholly on the Ni-P matrix. The real hardness of composite coatings cannot, therefore, be obtained, but it is nevertheless true that with increase of the B₄C content in the deposit coatings, the entire hardness increased.

Adhesive Force

A scratching test was adopted to measure the adhesive force of composite coatings. The results are shown in Fig. 5. The curve indicates that the higher the content of B₄C, the poorer the adhesive force.

Figure 6 shows the micrograph of the spot where the coatings strip during scratching. With the load on the Ni-P layer increasing (direction of arrow), it first appeared as a crack, then stripped large lumps, but on the Ni-P-32%B₄C coatings, only small lumps were stripped. It indicates that adding B₄C particles destroys the continuity of the Ni-P matrix and that Lc cannot be used to evaluate exactly the real adhesive force of composite coatings. Obviously, the force needed to cause stripping of large lumps is larger than the force to cause stripping of small lumps. Indentation and file tests qualitatively indicated that the Ni-P-B₄C composite coating has excellent adhesion to cast substrates.