New work item proposal – Glass beads for road materials – Determination of refractive index using secondary rainbow method

Dear Sir or Madam,

Please find attached a new work item proposal submitted by SAC (China) on Glass beads for road materials – Determination of refractive index using secondary rainbow method. It should be noted that, if the NWIP is approved, the work will be carried out in a Project Committee.

You are kindly invited to complete the ballot form (Form 05) which could be downloaded at www.iso.org/forms and send it, preferably in Word format, to the Secretariat of the ISO Technical Management Board at tmb@iso.org before 28 May 2012.

Yours faithfully,

Sophie Clivio
Secretary to the Technical Management Board

Encl: NWIP (Form 04)
A proposal for a new work item within the scope of an existing committee shall be submitted to the secretariat of that committee with a copy to the Central Secretariat and, in the case of a subcommittee, a copy to the secretariat of the parent technical committee. Proposals not within the scope of an existing committee shall be submitted to the secretariat of the ISO Technical Management Board.

The proposer of a new work item may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, or organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General.

The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information.

See overleaf for guidance on when to use this form.

**IMPORTANT NOTE:** Proposals without adequate justification risk rejection or referral to originator.

Guidelines for proposing and justifying a new work item are given overleaf.

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### Proposal (to be completed by the proposer)

<table>
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<tr>
<th>Title of proposal</th>
<th>Glass beads for road materials - Determination of refractive index using secondary rainbow method</th>
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<tr>
<td>English title</td>
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<tr>
<td>French title (if available)</td>
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**Scope of proposed project**

To provide a procedure for determining the refractive index of glass beads for road materials such as road marking materials and reflective films using the secondary rainbow method.

**Concerns known patented items** (see ISO/IEC Directives Part 1 for important guidance)

- [ ] Yes
- [x] No

*If “Yes”, provide full information as annex*

**Envisaged publication type** (indicate one of the following, if possible)

- [ ] International Standard
- [ ] Technical Specification
- [ ] Publicly Available Specification
- [ ] Technical Report

**Purpose and justification** (attach a separate page as annex, if necessary)

Please see Annex A

**Target date for availability** (date by which publication is considered to be necessary) 2014-08

**Proposed development track**

- [ ] 1 (24 months)
- [x] 2 (36 months - default)
- [ ] 3 (48 months)

**Relevant documents to be considered**

Please see Annex B

**Relationship of project to activities of other international bodies**

European Committee for Standardization

**Liaison organizations**

ISO TC 172/SC 3

**Need for coordination with:**

- [ ] IEC
- [ ] CEN
- [ ] Other (please specify)

**Preparatory work** (at a minimum an outline should be included with the proposal)

- [x] A draft is attached
- [ ] An outline is attached. It is possible to supply a draft by

The proposer or the proposer's organization is prepared to undertake the preparatory work required

- [ ] Yes
- [ ] No

**Proposed Project Leader** (name and address)

GUO Dong-hua
Add:8 Xitucheng Rd, Beijing, China 100088, Tel:86-010-82019588-9626, Fax:86-010-62370567,E-mail:dh.guo@rioh.cn

**Name and signature of the Proposer**

(name and contact information)

Mr.GUO Hui
Secretary General , Chinese Member Body of ISO
Fax:+86 10 82260660
E-mail:sac@sac.gov.cn
New work item proposal

Comments of the TC or SC Secretariat

Supplementary information relating to the proposal

☐ This proposal relates to a new ISO document;
☐ This proposal relates to the amendment/revision of an existing ISO document;
☐ This proposal relates to the adoption as an active project of an item currently registered as a Preliminary Work Item;
☐ This proposal relates to the re-establishment of a cancelled project as an active project.

Other:

Voting information

The ballot associated with this proposal comprises a vote on:

☐ Adoption of the proposal as a new project
☐ Adoption of the associated draft as a committee draft (CD)
☐ Adoption of the associated draft for submission for the enquiry vote (DIS or equivalent)

Other:

Annex(es) are included with this proposal (give details)

☒ 1. Design of refractive index test equipment of glass beads for road materials by secondary rainbow method
☒ 2. Draft of the International Standard

Date of circulation 2012-02-28
Closing date for voting 2012-05-28
Signature of the TC or SC Secretary

Use this form to propose:

a) a new ISO document (including a new part to an existing document), or the amendment/revision of an existing ISO document;
b) the establishment as an active project of a preliminary work item, or the re-establishment of a cancelled project;
c) the change in the type of an existing document, e.g. conversion of a Technical Specification into an International Standard.

This form is not intended for use to propose an action following a systematic review - use ISO Form 21 for that purpose.

Proposals for correction (i.e. proposals for a Technical Corrigendum) should be submitted in writing directly to the secretariat concerned.

Guidelines on the completion of a proposal for a new work item

(see also the ISO/IEC Directives Part 1)

a) Title: Indicate the subject of the proposed new work item.
b) Scope: Give a clear indication of the coverage of the proposed new work item. Indicate, for example, if this is a proposal for a new document, or a proposed change (amendment/revision). It is often helpful to indicate what is not covered (exclusions).
c) Envisaged publication type: Details of the types of ISO deliverable available are given in the ISO/IEC Directives, Part 1 and/or the associated ISO Supplement.
d) Purpose and justification: Give details based on a critical study of the following elements wherever practicable. Wherever possible reference should be made to information contained in the related TC Business Plan.

1) The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems it is expected to solve or the difficulties it is intended to overcome.

2) The main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments, distributors.

3) Feasibility of the activity: Are there factors that could hinder the successful establishment or global application of the standard?

4) Timeliness of the standard to be produced: Is the technology reasonably stabilized? If not, how much time is likely to be available before advances in technology may render the proposed standard outdated? Is the proposed standard required as a basis for the future development of the technology in question?

5) Urgency of the activity, considering the needs of other fields or organizations. Indicate target date and, when a series of standards is proposed, suggest priorities.

6) The benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantage(s) if no standard is established within a reasonable time. Data such as product volume or value of trade should be included and quantified.

7) If the standardization activity is, or is likely to be, the subject of regulations or to require the harmonization of existing regulations, this should be indicated.

If a series of new work items is proposed having a common purpose and justification, a common proposal may be drafted including all elements to be clarified and enumerating the titles and scopes of each individual item.

e) Relevant documents and their effects on global relevancy: List any known relevant documents (such as standards and regulations), regardless of their source. When the proposer considers that an existing well-established document may be acceptable as a standard (with or without amendment), indicate this with appropriate justification and attach a copy to the proposal.

f) Cooperation and liaison: List relevant organizations or bodies with which cooperation and liaison should exist.
Annex A

Purpose and justification

a) The specific aims and reasons for the standardization activity

Glass beads are the key component of the retroreflective road materials. The refractive index of the glass beads is a key parameter affecting the optical performance of the retroreflective road materials.

Direct accurate measurement of the refractive index of the glass materials is usually based on the minimum deviation angle prism method or the total reflection critical angle method, in which the samples must be made to form a certain size precise prism in order to measure. But for the granular glass materials such as glass beads, the method by making the prism to measure the refractive index is time-consuming and not directly reflecting the actual situation.

The immersion fluid method is the most commonly used method for measuring the refractive index of the glass beads. Almost all developed standards relate to the glass bead used in the road materials in the world provide the immersion fluid method as sole refractive index test method.

The immersion fluid method is effective for the low refractive index glass beads. But for the high refractive index glass beads with the refractive index not less than 1.9, because the necessary high refractive index matching fluids are toxic, it is very inconvenience to the measurement.

Additionally, for the immersion test method, the refractive index is obtained by comparing the glass beads of unknown refractive index with matching fluids of known refractive index, so that the specific values of refractive index of the measured glass beads can’t be obtained. This brings a lot of inconvenience for the occasion required the specific values, such as the production of high-strength grade reflective film.

In order to abstain above limitations, there are some substitute refractive index test methods, such as rainbow method, interferometric method, melting solid media comparison method, wherein the rainbow method is researched in a greater ranges than other methods.

In China, through joint research, Research Institute of Highway Ministry of Transport and Sichuan University have developed a refractive index test device by use of secondary rainbow phenomenon occurring when the glass beads are illuminated by the laser rays. While the feasible experiments have been carry out basing on tests of a large number of glass bead samples using the device. So we provide the proposed standard seeking to provide a safe and accuracy method for determination of refractive index of the glass beads for road materials.
b) The main interests that might benefit from or be affected by the activity

- Glass bead producers
- Glass bead consumers
- Road governing agencies
- Glass bead research agencies
- Glass bead equipment producers

c) Feasibility of the activity

The principle of secondary rainbow involved by this method has been the field-based staff recognition. We designed and stereotyped the test equipment of refractive index of glass bead based on this principle, while have carried out a large number of test match work with immersion test method. The results show that the secondary rainbow test method can meet the testing requirements of refractive index of glass beads for road materials. Additionally, the secondary rainbow method has higher accuracy and security features. Basing on the obtained research results, after further discussed, forming the International Standard is feasible.

d) Timeliness of the standards to be developed

The proposal first provides the secondary rainbow method as the test method of refractive index of glass beads for road materials in the world. The relative invention patents have been applied and are in the process. In accordance with the patent for the procedure, need 2 years of time to grant the patent right. At the same time, the need for States to approach relevant for the comparison test, also requires 2 years or so.

e) Urgency of the activity

Prior to this proposal, the immersion method is main test method for the refractive index of glass beads for road materials. The main drawbacks of the immersion method are two points. One is that the high refractive index matching liquid is toxic to the human body, and two is that the method can’t achieve accurate measurements, and can’t meet the need for accurate values of the refractive index of glass beads required in some occasions. The secondary rainbow test method for the refractive index of glass beads provided by the proposal, once recognized, can solve these two problems, the need of this method is urgency.

The target date for completion of this International Standard will be determined by the ISO Working Group, but should be within 3 years (i.e consistent with the normal, "default" standards development track).

f) The benefits expected from implementation of the standard

It is expected that the standard will

- provide a safe, substituted the immersion method, test method for the refractive index of glass beads for road materials;
• provide an accurate test method for the refractive index of glass beads for road materials;
• facilitate trade liberalization and remove trade barriers (implement open and fair trade).
### Annex B

#### Relevant documents to be considered

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<th>Sponsoring Organization</th>
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<td>GB/T 24722-2009</td>
<td>Glass Beads for Road Markings</td>
<td>Standardization Administration of the People's Republic of China</td>
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<tr>
<td>CNS 4342-1989</td>
<td>Glass Beads for Reflective Traffic Paint</td>
<td>Inspection Bureau of Standards, Taiwan</td>
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<tr>
<td>CNS 4343-1989</td>
<td>Method of Test for Glass Beads for Reflective Paint</td>
<td>Inspection Bureau of Standards, Taiwan</td>
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<td>KS L2521-2006</td>
<td>Glass Beads for Traffic Paint</td>
<td>Korean Standards Association</td>
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<tr>
<td>AASHTO M 247-08</td>
<td>Glass Beads Used in Traffic Paint</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>TT-B-1325D</td>
<td>Federal Specification - Beads(Glass Spheres)Retro-Reflective</td>
<td>U.S. General Services Administration</td>
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Glass beads for road materials - Determination of refractive index using secondary rainbow method

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TC or SC within the framework of which the draft has been prepared]

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO nnn-n was prepared by Technical Committee ISO/TC241, Road Safety Management.
Introduction

The refractive index of the glass beads for road materials can be measured by use of the secondary rainbow method. Using the laser with a special wave length as a light source and obtaining the minimum deviation angle of the secondary rainbow, the refractive index of the glass bead samples can be statistically obtain.
Glass beads for road materials - Determination of refractive index using secondary rainbow method

1 Scope

This International Standard describes a procedure for determining the refractive index of glass beads for road materials such as road marking materials and reflective films using the secondary rainbow method.

The results obtained using the methods described in this International Standard are applicable to the glass beads with the diameter less than 1700μm, the refractive index not less than 1.9.

2 Principle

Under the condition of laser illumination, the light will emit out the glass bead after through one, two or multiple times internal reflection, forming the deviation angle between exit light ray and incident light ray. Lights near the minimum deviation angle are the most intensive, and intensive light rays form a rainbow.

Measure the ring radius of the secondary rainbow forming in the direction of the incident beam, and the distance between the measured glass bead and the secondary rainbow ring. According to equation (1), the minimum deviation angle can be calculated, than obtaining the refractive index of the glass bead basing on equation (2). Measure not less than 200 glass beads, and statistically analyze the average value of refractive index of the glass beads samples.

\[
\theta_{\text{min}} = \tan^{-1}\left(\frac{r}{s}\right) \quad (1)
\]

where

- \( \theta_{\text{min}} \) is the minimum deviation angle, in degrees;
- \( r \) is the secondary rainbow ring radius, in millimeters;
- \( s \) is the distance between the measured glass bead and the secondary rainbow ring, in millimetres.

\[
\theta_{\text{min}} = k\pi + 2\arcsin\left(\frac{(k+1)^2-n^2}{k(k+2)}\right) - 2(k+1)\arcsin\left(\frac{1}{n}\sqrt{\frac{(k+1)^2-n^2}{k(k+2)}}\right) \quad (2)
\]

where

- \( n \) is the refractive index, in millimetres;
- \( k \) is the number of internal reflection.
3 Apparatus

3.1 Optical test apparatus of the secondary rainbow

Optical test apparatus of the secondary rainbow include laser, mirrors, lens, aperture, X, Y translation structure, lifting device, reading device, imaging system. Apparatus schematic is shown in figure 1 and figure 2.

![Figure 1 —Top view of optical test apparatus of the secondary rainbow](image1)

**Key**

1. Laser
2. The first mirror
3. Lens
4. The secondary mirror
5. Aperture
6. The third mirror
7. X, Y translation structure
8. Slide
9. Glass bead
10. Receiving screen
11. Camera
12. Lifting knob
13. Readout
14. Tripod
15. Capture card

![Figure 2 —Side view of optical test apparatus of the secondary rainbow](image2)
3.1.1 Laser
Single-mode helium-neon laser with a wavelength of 632.8nm and about a power of 2mw.

3.1.2 Mirrors
Set on the laser light rays path, in total of three pieces, used to ensure that the laser light rays vertically upward illuminate the glass beads.

3.1.3 Lens
The lens should be a long focal length positive lens.

3.1.4 Aperture
Able to filter out the stray light introduced in the transmission process of the laser.

3.1.5 X, Y translation structure
Support the slide, with a screw mechanism or a gear rack mechanism. X-axis, Y axis is each adjustable.

3.1.6 Lifting devices
Include a tripod and a lifting platform. The tripod connects the lifting platform. By adjusting the lifting knob to change the height of the lifting platform. A camera is installed on the upper part of the lifting platform, the lower part of which is a receiving screen.

3.1.7 Readout
Installed on the side of the lifting platform, with a resolution of 0.01mm.

3.1.8 Imaging system
Compose of a camera, receiving screen, capture card and computer. The camera can photograph the secondary rainbow images. The images shall be transmitted into the capture card and be analyzed by the computer.

3.2 Oven
With forced-air convection, maintained at 105°C ~ 110°C.

3.3 Dryer
With a desiccant, such as silica gel.

4 Preparation of test samples
For each type of the glass bead, test samples should be able to ensure that not less than 200 glass beads are on effective measurement.

The test samples shall be dried for 1h at a oven maintained at 105°C ~ 110°C, and cooled to room temperature in a dryer for use.
5 Calibration requirements

In order to measure the radius of the secondary rainbow, it is necessary of calibrating to measure the size of a pixel, on which the radius of the secondary rainbow can be calculated, as follows:

A calibrating ring with a diameter of $L$ shall be set on the location of the receive screen. Photograph the image of the calibrating ring and transmit it into the computer. Measure the number of pixels contained in the segment with a length of $L$, on which the size of one pixel can be calculated.

Open a photographed secondary rainbow image and measure the number of pixels of the image included in the range of diameter. Calculate the radius of the secondary rainbow basing on equation (3).

$$ r = \frac{M \times L}{2 \times m} $$

where

- $M$ is the number of pixels of the secondary rainbow image included in the range of diameter;
- $L$ is the diameter of the calibrating ring;
- $m$ is the number of pixels contained in the segment with a length of $L$.

6 Procedures

6.1 Environmental conditions

6.1.1 Test should be carried out under dark conditions.

6.1.2 Test temperature 23 °C ± 2 °C, humidity 50% RH ± 5% RH.

6.2 Test procedures

6.2.1 Lay amount of glass bead samples on the slide forming a single layer of glass beads.

6.2.2 Place the slide on the X, Y translation structure of the optical test apparatus of the secondary rainbow, and start the apparatus.

6.2.3 Adjust X, Y translation structure, so that the laser rays illuminating the glass bead samples, obtaining a second rainbow image on the receiving screen.

6.2.4 Rotate the lifting knob, getting a clear secondary rainbow image with an appropriate size.

6.2.5 Processing by imaging system, obtain the radius of the secondary rainbow ring. Read the distance between the measured glass bead and rainbow ring shown on the readout.

6.2.6 Calculate the minimum deviation angle according to equation (1).

6.2.7 Calculate the refractive index of the measured glass bead basing on equation (2) by the minimum deviation angle, wherein the number of internal reflection is 2.
6.2.8  Continue 6.2.3-6.2.7 steps to implement a total of not less than 200 measurements, and take the refractive index on average, accurate to 0.1.

7  Accuracy

Accuracy data are mainly base on the error caused by non-roundness of the glass beads. Non-round glass beads will form a non-round secondary rainbow ring, which will result in errors. So it is necessary to choose the glass bead samples with good roundness, while taking multiple measurements (at least 200 tests) to reduce the impact of roundness.

8  Test report

The test report shall include the following:

a)  a reference to this International Standards;

b)  all details necessary for complete identification of the material or product tested;

c)  the type of test samples used and the method of preparation, stating the mass of the samples;

d)  any incidents likely to have affected the results;

e)  the refractive index of the glass beads;

f)  the date(s) of testing.
Design of Refractive Index Test Equipment of Glass Beads for Road Materials by Secondary Rainbow Method

Introduction

Glass beads are the key component of the retroreflective road materials. The refractive index of the glass beads is a very important parameter affecting the optical performance of the retroreflective road materials.

Direct accurate measurement of the refractive index of the glass materials is usually based on the minimum deviation angle prism method or the total reflection critical angle method, in which the samples must be made to form a certain size precise prism in order to measure. But for the granular glass materials such as glass beads, the method by making the prism to measure the refractive index is time-consuming and not directly reflecting the actual situation[1].

The immersion fluid method is the most commonly used method for measuring the refractive index of the glass beads for road materials. The immersion fluid method is effective for the low refractive index glass beads. But for the high refractive index glass beads with the refractive index not less than 1.9, because the necessary high refractive index matching fluids are toxic, it is very inconvenient to the measurement.

The secondary rainbow method is a fast, accurate and safe method for measuring the refractive index of glass beads. Under the condition of illumination, the light will emit out the glass bead after through two times internal reflection, forming the deviation angle between the exit light ray and incident light ray. After measuring the minimum deviation angle, the refractive index of the glass beads can be obtained.

In this paper, basing on the theory of the secondary rainbow, we provide a test method of refractive index of glass beads for road materials and design a set of test equipment related to the method. Furthermore, verify the feasibility of the equipment trough measuring amount of glass bead samples and analyze the cause of error and measurement accuracy.

Testing theory of the secondary rainbow method

Under the condition of the laser illumination in the air, the light will emit out the glass bead after through one, two or multiple times internal reflection, forming the deviation angle between the exit light ray and incident light ray, as shown in Figure 1. Lights near the minimum deviation angle are the most intensive, and the intensive light rays form a rainbow.

![Figure 1. Ray refracted and reflected by a glass bead](image-url)
After the light rays pass through $k$ times internal reflection within a glass bead with the refractive index of $n$, wherein the angle of incidence and refraction of the light rays is each expressed as $i$ and $z$, the deviation angle $\theta$ can be expressed as

$$\theta = k\pi + 2i - 2z(k + 1) \quad (1)$$

Because $i$ and $z$ meet Snell theorem $\sin i = n \sin z$, substituted into the equation (1) and in the condition of $n < k + 1$, the relationship among the minimum deviation angle $\theta_{\text{min}}$, times of internal reflection $k$, and refractive index of glass bead $n$ can obtain as

$$\theta_{\text{min}} = k\pi + 2\arcsin\left(\frac{(k + 1)^2 - n^2}{k(k + 2)}\right) - 2(k + 1)\arcsin\left(\frac{1}{n}\sqrt{\frac{(k + 1)^2 - n^2}{k(k + 2)}}\right) \quad (2)$$

When the times of internal reflection $k$ is identified as 2 (forming the secondary rainbow), measured $\theta_{\text{min}}$, the refractive index of the glass beads $n$ can be calculated by equation (2).

**Optical design**

In order to test the minimum deviation angle $\theta_{\text{min}}$, we carry on an optical design as shown in Figure 2. Where the light source is the single-mode helium-neon laser with a wavelength of 632.8nm and a power of about 2mw. The beams emitted from the laser focus on the glass bead through the lens, and are filtered the stray light produced in the transmission process using an aperture. The receiving screen shall receive the secondary rainbow fringe image of the glass bead, where the centre of receiving screen is set a block light device to block the zero order diffraction beams.

![Optical design](image)

**Key**

1 Laser, 2 Lens, 3 Aperture, 4 Glass bead, 5 Slide, 6 Receiving screen, 7 Camera

**Figure 2. Optical design**

As the long depth of focus for the lens, the laser beams converge to the glass bead can be approximated as the parallel light, which will cause the rainbow phenomenon after projecting the glass bead. In theory, the above optical design, in addition to forming the primary and secondary rainbow, there is likely to form the high-order rainbow.

However, due to the transmittance of the high refractive index glass beads is very low (about several per cent), only the primary and secondary rainbow can generally be observed in such optical design. According to the nature of the high refractive index glass bead, one rainbow appears in the opposite direction of the incident beam, while the second rainbow appears in the incident beam direction. Therefore, the receiving screen behind the glass bead shall receive the secondary rainbow fringe image of the glass bead, as shown in Figure 3.
Measure the bright ring radius of secondary rainbow fringe image of the glass bead $r$ and distance between the glass bead and the receiving screen $s$, as shown in Figure 4. The minimum deviation angle of the secondary rainbow of the glass bead under test can be calculated by the equation (3). Put the result into the equation (2), and taking $k = 2$, the refractive index of the glass bead $n$ can be calculated.

\[
\theta_{\text{min}} = \tan^{-1}\left(\frac{r}{s}\right)
\]  

(3)

**Equipment structure**

According to the optical design, we design an refractive index test equipment basing on the secondary rainbow method. The structure of the equipment is shown as Figure 5.

The laser emits laser beams. The laser beams are reflected by the first mirror and pass through the lens. The light beams of transmission are reflected by the secondary mirror. The light beams pass through an aperture, and then are reflected by the third mirror. The beams straight up on and pass through the slide on the loading platform. Use the X, Y translation structure to adjust the slide so that
the beams shine on the glass beads. A secondary rainbow image will be received on the receiving screen. At this time, rotate the lifting knob set on the tripod to observe the image of the secondary rainbow, which camera can take to an appropriate size and clear image of the secondary rainbow. Read out the reading of the readout as the distance value between the glass bead and receiving screen, and the diameter of the rainbow ring captured by the capture card. According the above distance value and diameter, the refractive index of the glass bead can be calculated. For each type of glass beads, it is necessary to measure not less than 200 glass beads and statically count the refractive index by the computer. The typical data of the type 1#-1 glass beads are shown in table 1 and Figure 6.

### Table 1. Statistical data of refractive index of the type 1#-1 glass beads

<table>
<thead>
<tr>
<th>Average</th>
<th>1.914</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

![Figure 6. Histogram of test results of the refractive index](image)

As shown in the histogram, the test results close to the normal distribution and the typical data of the refractive index is 1.914.

**Calibration**

In order to measure the radius of the secondary rainbow, it is necessary to calibrate to measure the size of one pixel, which can calculate the radius of the secondary rainbow. That is, firstly measure the number of pixels \( m \) contained in the range of diameter of the ring \( L \), which can calculate one pixel size: \( L / m \).

Open the captured secondary rainbow image and measure the number of pixels \( M \) contained in the diameter of the secondary rainbow, obtaining the radius of the secondary rainbow: \( M \times L / (2 \times m) \).

**Error and measurement accuracy**

Non-round glass beads will load to appear a non-round ring of the secondary rainbow, which will result in error. So it is necessary to choose a good glass bead samples with good roundness, taking multiple times measurement averaging method to reduce the effects of roundness.
When measuring the radius of the secondary rainbow ring, the outer of the secondary rainbow has some noise, so there will be some error of the readings. Accuracy of measuring for radius is ± 4 pixels, resulting to an error about 0.032mm. In addition, the accuracy of the distance measurement is 0.03mm.

Since the minimum deviation angle and refractive index of the glass beads all are obtained by geometry, so there will be some error. But this error is very small, so in the context of the measurement, it can be neglected.

Because the value of the refractive index of the glass beads for road materials usually accurate to 0.1, through testing using glass beads with different sizes, we find the designed equipment can meet this accuracy requirement, as table 2 shown.

**Table 2. Test results of refractive index of different types of glass beads for road materials**

<table>
<thead>
<tr>
<th>Code</th>
<th>Sizes/μm</th>
<th>Values</th>
<th>Code</th>
<th>Sizes/μm</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#-1</td>
<td>90-100</td>
<td>Average 1.914118</td>
<td>2#-1</td>
<td>90-100</td>
<td>Average 2.17913</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.002546</td>
<td></td>
<td></td>
<td>Standard deviation 0.00976</td>
</tr>
<tr>
<td>1#-2</td>
<td>80-90</td>
<td>Average 1.92386</td>
<td>2#-2</td>
<td>80-90</td>
<td>Average 2.1862</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.00714</td>
<td></td>
<td></td>
<td>Standard deviation 0.00474</td>
</tr>
<tr>
<td>1#-3</td>
<td>75-80</td>
<td>Average 1.92889</td>
<td>2#-3</td>
<td>75-80</td>
<td>Average 2.16704</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.00085</td>
<td></td>
<td></td>
<td>Standard deviation 0.00154</td>
</tr>
<tr>
<td>1#-4</td>
<td>63-75</td>
<td>Average 1.92158</td>
<td>2#-4</td>
<td>63-75</td>
<td>Average 2.1634</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.00028</td>
<td></td>
<td></td>
<td>Standard deviation 0.03019</td>
</tr>
<tr>
<td>1#-5</td>
<td>53-63</td>
<td>Average 1.92227</td>
<td>2#-5</td>
<td>53-63</td>
<td>Average 2.16733</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.00484</td>
<td></td>
<td></td>
<td>Standard deviation 0.01662</td>
</tr>
<tr>
<td>1#-6</td>
<td>45-53</td>
<td>Average 1.924689</td>
<td>2#-6</td>
<td>45-53</td>
<td>Average 2.16883</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.011526</td>
<td></td>
<td></td>
<td>Standard deviation 0.00948</td>
</tr>
<tr>
<td>1#-7</td>
<td>38-45</td>
<td>Average 1.898328</td>
<td>2#-7</td>
<td>38-45</td>
<td>Average 2.15804</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation 0.009776</td>
<td></td>
<td></td>
<td>Standard deviation 0.00255</td>
</tr>
</tbody>
</table>

In addition, light sources can affect the results of the refractive index. But the errors are only shown in the position of 0.01, so the designed equipment is ok for the test of the refractive index of the glass beads for road materials.

**Conclusion**

Using the laser as the light source to emit the parallel beams and basing on the secondary rainbow theory, design a set of equipment for testing the refractive index of the high refractive index glass beads used in road materials. The glass beads are put on the slide of the equipment, and the laser beams vertically upward illuminate the glass beads. In such mode, the glass beads are not easy to fall off, and can be repeatedly measured in the testing process.

Just adjusting the X, Y translation structure, the beams can illuminate the glass beads and a secondary rainbow image can be obtained on the receiving screen, reducing the error producing from the alignment between the laser beams and the glass bead.

Take the secondary rainbow images using camera and use the computer carry out a statistical analysis of the refractive index of the glass beads to improve the accuracy of calculation.

**References**