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Yake effects in various telescope mirrors

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Abstract. The yake effect in the 56 cm and the 38 cm pyrex mirrors of the Uttar Pradesh State Observatory is described. Similar effects elsewhere are also discussed.

Key words : telescope mirrors—yake effect

1. Introduction

The Yake phenomenon has been defined as spontaneously deteriorated areas of any glass surface that differ from the mother surface in reflectivity, scattering power, and other properties (Kinosita 1965). We can distinguish between two types of yakes : Ao-yake (Ao = blue) and Shiro-yake (Shiro = white). The Aoyake often appears as amber or purple-blue coloured stains on the glass surface and these patches on the glass surface are similar to the surface produced by means of acid-leaching. The Shiroyake is described as white stains which are patches where light is scattered by small crystallites or other microscopic irregularities adhering to the glass surface.

It has been generally found that Aoyake is more severe form of Shiroyake. Shiroyake, in course of time and deteriorating conditions, leads to Aoyake layers, and an Aoyake layer is found below a Shiroyake layer. According to Kinosito, the nearest equivalent English term for yake is 'Stains' or 'Tarnishing'.

We discuss here the yake phenomena in the 56 cm and the 38 cm pyrex mirrors at the Uttar Pradesh State Observatory, Naini Tal (UPSO). Two low-expansion mirrors, 122 cm at Dominion Astrophysical Observatory (DAO) and the 75 cm at Copenhagen University Observatory (CUO), are also discussed.

2. Problem mirrors

(*i*) *UPSO pyrex mirrors* : The observatory imported the optics and the telescope tube for a 56 cm telescope from Cox, Hargreaves & Thomson Ltd., UK in 1959, The primary mirror of this telescope was made of yellow coloured pyrex glass blank having significant air bubbles and striae, moulded by Pilkington Bros.

The telescope became operational in 1959 and worked quite well for 15 years. A few white patches were seen on the surface of the mirror in 1974, during cleaning for aluminization. These unusual stains could not be removed by the normal cleaning procedures. In time these patches grew and appeared blue coloured on the mirror surface and in 1980-81, it was observed that nearly the whole surface of the mirror was afflicted with the formation of this blue coloured film-structure which drastically deteriorated the paraboloidal figure of the mirror. The mirror surface under this condition could not retain the coated aluminium for long.

On the assumption that smoothing and polishing of the mirror could perhaps rectify the situation, smoothing was started in 1981 December and the white films reappeared after a few weeks. These white films reappeared five times before the mirror was installed back into the telescope in 1985 November. The Ronchigrams shown in figures 1 and 2 show the nature of the mirror surface in 1982 January and 1985 September respectively. Since this pyrex blank could not be trusted, a new zerodur mirror has been fabricated (figure 3).

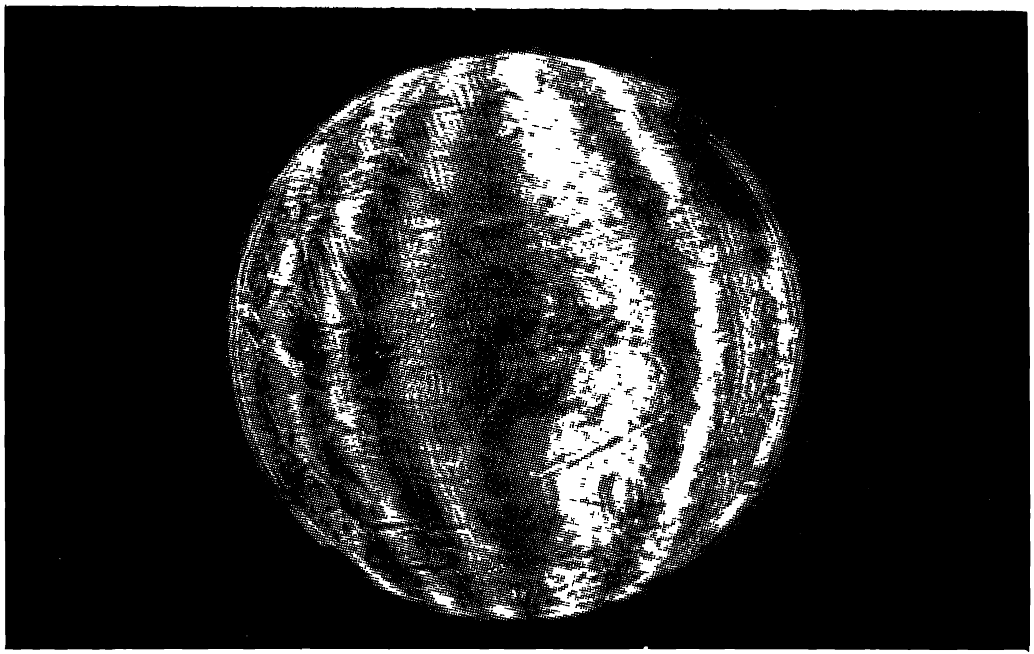

Figure 1. Ronchigram of the 56 cm pyrex mirror with yake layers and other defects.

The observatory acquired the 38 cm telescope from Fecker, USA in 1959, whose pyrex primary mirror blank is colourless. During annual realuminization in 1982, a few white films were observed on a few zones of this mirror which appeared clearly to follow the developments similar to those observed with the 56 cm mirror. The mirror is now under close observation.

(*ii*) *Copenhagen mirror* : Copenhagen University Observatory (CUO) commissioned a 75 cm Schmidt telescope in 1965–66 whose low expansion primary mirror blank was moulded by Pilkington Bros & figured by Carl Zeiss Jena. (Anderson 1986, personal communication). The trouble with this mirror started after three

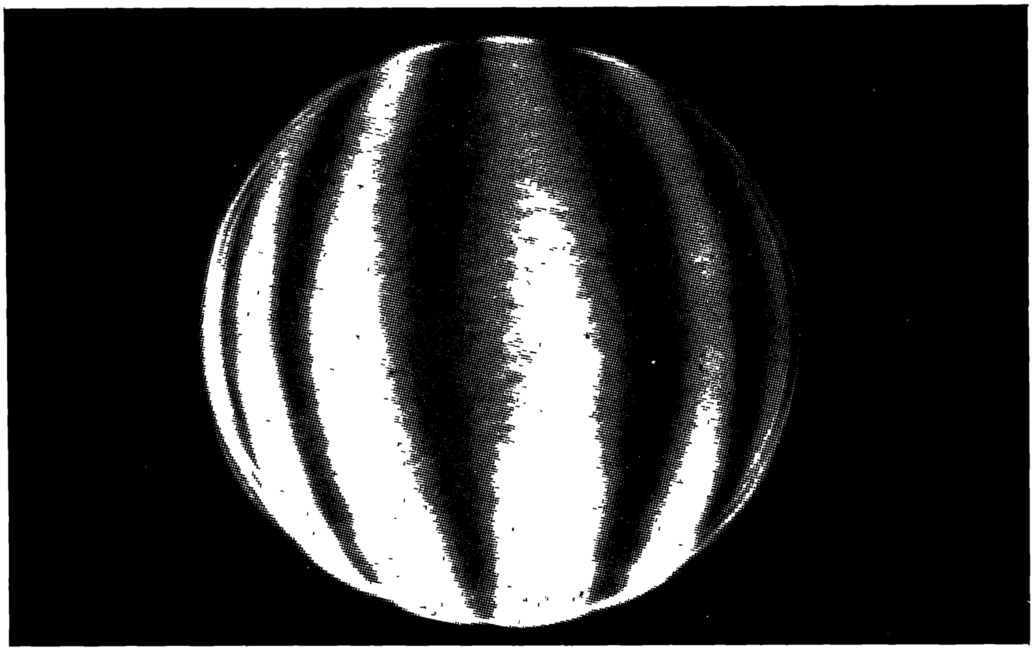

Figure 2. Ronchigram of the 56 cm pyrex mirror after refiguring.

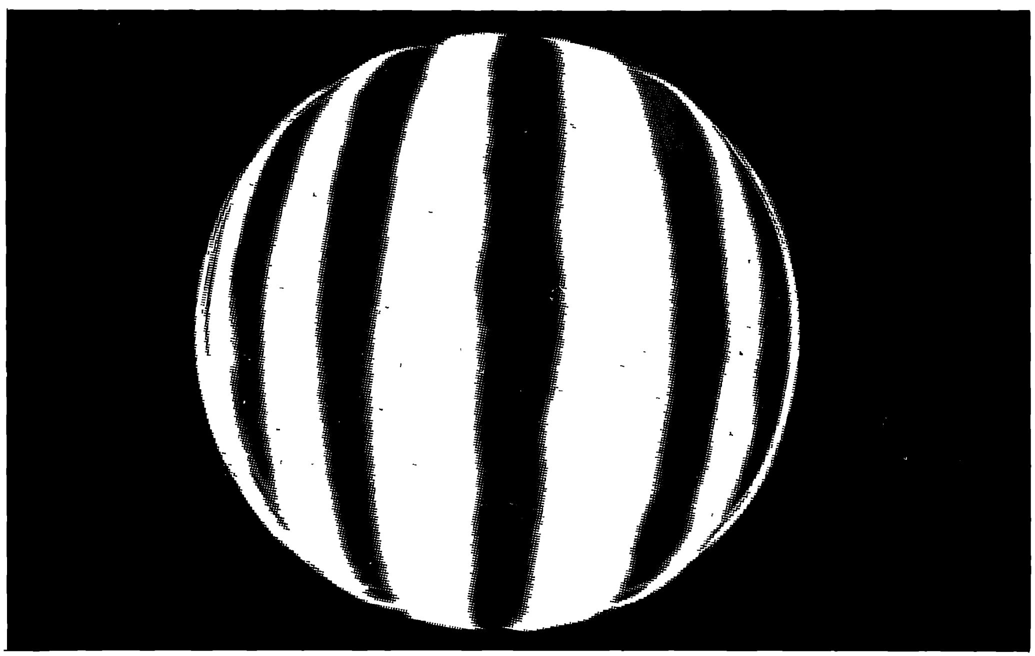

Figure 3. Ronchigram of the 56 cm zerodur replacement mirror.

years during realuminization. Many holes on the aluminium film developed after about two weeks, grew to 2–3 cm size within a few weeks, and the coating disappeared frequently. The position and shape of these zones kept on changing. Various cleaning techniques were tried, however no permanent solution could be achieved and the mirror was replaced with a zerodur mirror in 1971–72.

Keeping in view the extremely short operational period of six years, it seems reasonable that no coloured films were reported on this mirror. However, the occurrence of a very thin colourless/white film cannot be ruled out.

(*iii*) *DAO mirrors* : DAO commissioned a 122 cm telescope in 1961–62 and the primary low-expansion mirror was moulded by Chance Bros (Horne 1980). After about 10 yr, this mirror showed a phenomenon similar to that observed with the Copenhagen 75 cm mirror, and nearly 5% surface area of the coated mirror was affected by disappearance of aluminium patches of nearly 1 cm size. The recurrent growth of these patches forced its realuminization after every few weeks (Fletcher 1985, personal communication). The irreparable colour films had already developed on this mirror, similar to those observed with the 56 cm Naini Tal mirror (*cf.* Kinosita 1965).

In 1975–76, just after aluminization, white patchy areas could be observed on the surface of this mirror. These zones never repeated their locations nor could they be correlated with the positions of the holes in the aluminium coating.

DAO optics shop started fabricating a replacement very-low expansion mirror in 1981–82, which was installed in 1985 April (Van den Bergh 1986).

Another telescope mirror was rejected at DAO (Enright 1986). The 1.83 m telescope was commissioned in 1917–18, with a Crown primary mirror. After about 45 to 50 year, it became apparent that at times of good seeing, the mirror figure was not adequate because the surface had developed many undesirable zones which contributed to easily seen structures in the images. The aluminium coating was satisfactory in this mirror, but in 1970 it was replaced with a cervit mirror which has successfully produced the desired quality images (Fletcher 1986, private communication).

3. Probable causes

(*i*) *Blank-moulding limitations* : The exact proportions of different constituents of the raw materials and their thorough mixing is important to prevent the possible segregation after mixing as proved photographically by Jebsen Marwedel in his work '*Microscopical examination of glass melting*' described by Shand (1958).

It has been reported that 'mixing' during the blank's moulding was not probably upto the mark in the UPSO 56 cm, the CUO 75 cm, and the DAO 122 cm mirrors. This led to the blank-glasses being made up of a 'soft' component. and a 'hard' component. The softer component readily leached out to produce the films.

The DAO-glass manufacturer, has reported the improper mixing in a few batches of glass blanks moulded during 1950s. The improper mixing was discovered by the manufacturers some years after marketing the blanks.

Amur (1983) has theoretically studied in some detail the material parameters that determine the surface accuracy of large astronomical mirrors. He has shown that the excellent quality of telescope mirrors can be pre-determined by a careful selection of the blank material and observance of the optimum conditions for polishing it.

These findings were utilized in the USSR during the fabrication of the 1.15 m to 6 m telescope mirrors. The 3.6 m of ESO, 3.8 m of AAT and 4 m of KPNO telescope mirrors are rated as of high quality. The first plates with the 6 m telescope were obtained in 1975 (Shabanov & Korovjakovsky 1978). The 6 m mirror then gave a light concentration of 91% within 1 arcsec which is close to the performance of 5.1 m Palomar telescope.

Puryaev & Gorshkov (1980) mention that the second parabolic mirror of the 6 m telescope was made (probably in 1978–79) to replace the first mirror.

In contrast, the pyrex blank of the second largest Mount Palomar 5.1 m telescope was moulded after several trials, in the 1930s (Wright 1951).

(*ii*) *Cleaning limitations* : The experience with the problematic mirrors at UPSO, CUO, and DAO suggests that these blanks are rather susceptible even to the normal cleaning procedures. The outgassing of the used chemicals acts as catalyst in the formation of the troubelsome films. The 'soft' component of glass may easily get affected by the action of the chemicals.

The UPSO 56 cm mirror had been treated on a few occasions with chromic acid and with a mixture of hydrofluoric acid and nitric acid in a proportion specified by Roth 1976 to see whether the unwanted films could be removed. It is also known that fused silica mirror surface is much more resistant to caustic attack than the pyrex, which shows that cleaning procedures do affect the durability of astronomical mirrors (Mann 1966).

(*iii*) *Weathering effects* : Weathering of optical surfaces occurs due to influence of atmospheric vapours, basically the hydrolysis of the alkali silicates producing alkali hydroxides and colloidal silicic acid. The alkali hydroxides then react with carbon dioxide present in the air, forming a film carbonate, with a separation of silica component.

Necessary precautions must be taken so that during blank-moulding the time taken to complete the operation must not allow the occurrence of devitrification. The tendency to devitrify can be reduced by decreasing lime and increasing soda although at the expense of weathering properties (Horne 1972).

The relative humidity is quite high at Naini Tal just before, during, and just after the monsoon season; and during winters at Victoria. Therefore, the contribution of this factor might have been considerable, besides temperature-cycling in the problem mirrors.

Puryaev *et al.* (1982) have described an accurate method for testing a 2.6 m devitrified glass mirror for astronomy. The mean square deviation in the shape of the mirror-surface with respect to a comparison paraboloid was 0.3 of an interference fringe in this case.

(*iv*) *The aging of glass surfaces* : Optical aging can be defined as the degree of deterioration of optical components with time (Pfund 1946). His work is based on the observations made with an instrument for determining refractive indices by Brewsterian angle.

Glass is looked upon as having aged 'normally' if it is exposed to ambient air and atmospheric pressure and at room temperature in an average physical laboratory. In contrast, the artificially produced aging is termed as 'accelerated' aging.

The studies of infrared reflections from fresh and aged glass surfaces show that the two modes of aging produce the same type of surface films, either whitish or coloured. Pfund also showed that the surface film on aged glass is due to the removal of more readily attacked constituent of glass and the remaining of an inert film of pure amorphous silica. When these observations are coupled with those of Vasicek (1940) it appears that the formation of the surface film on aged fused silica glass is highly probable. Therefore, in case of telescope mirrors, the aging factor also implies additional unacceptable losses.

4. Conclusion

Evidently no general rule can be laid down for estimating the working lives of astronomical mirrors, specific problem mirrors have to be seriously examined and worked upon.

Yokota *et al.* (1969) have found by ellipsometry that the refractive index of the Yake layer n_t is less than the refractive index of the bulk-glass n_b for glasses which are susceptible to weathering whereas n_b is less than n_t for chemically durable glasses. This can be used to check the supposition regarding Yake layers formation on telescope mirrors.

The experience with ceramic materials in astronomical community has not been as prolonged as with pyrex and other low-expansion glasses. However, it is quite probable that the ceramic materials shall have longer durability as useful telescope mirror substrates.

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