Original Paper

Analysis of various plunger materials used in the container glass industry[1)]

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The achievement of high impact strength has a basic influence on the further development of lightweight container glass. The tested articles were 1 l nonreturnable flint glass water bottles, produced in the NNPB process. The impact strength of the flint container glass ware was tested by repeated hitting on the upper contact area in the shoulder. Four different plunger materials were tested in a 12 section AIS Emhart machine. The test run was structured in an experimental and an analytical part. The paper includes graphic and diagrammatic interpretations concerning the impact strength, the elements from the plunger materials contained in the glass and furthermore the change in the chemical composition of the plunger material after use. The aim of this analysis was to find an ideal plunger material, which satisfies the requirements of higher strength for lightweight glass containers.

Untersuchungen zum Einsatz unterschiedlicher Pegelmaterialien in der Hohlglasindustrie

Für die weitere Entwicklung von Leichtgewichtglas ist das Erzielen einer hohen Schlagfestigkeit von großer Bedeutung. Untersuchungsgegenstand der Arbeit war eine im Enghals-Preß-Blas-Verfahren hergestellte 1 l-Einweg-Wasserflasche. Die Schlagfestigkeit von weißen Hohlglasbehältern wurde durch wiederholte Schläge auf die obere Berührzone überprüft. Vier verschiedene Pegelmaterialien wurden in einer 12-Stationen-AIS-Maschine getestet. Der Versuch bestand aus einem experimentellen und einem analytischen Teil. Der Beitrag enthält graphische Auswertungen hinsichtlich der Schlagfestigkeitswerte, der Elemente, die durch das Pegelmaterial ins Glas gelangt sind, und den Veränderungen der chemischen Zusammensetzung des Pegelmaterials im gebrauchten gegenüber dem neuen Zustand. Ziel der Untersuchung war, ein geeignetes Pegelmaterial zu finden, das den Erfordernissen für Leichtgewichtsglas mit hohen Festigkeitswerten genügt.

1. Introduction

The advancing development of the lightweighting process requires more stability and higher impact strength as important quality aspects. Especially the lower values of the impact strength have to be improved. Infringement caused by plunger material is assumed to be the cause of unsatisfactory values and has been made the topic of this investigation. The industrial glass manufacturing process on IS machines is influenced by many different machine parameters. This causes the supposition that the standby time of the plunger and the corresponding dynamic process have a basic influence on the impact strength. The avoidance of infringements on internal surfaces of the container glass products is therefore the important issue. Abrasion particles as check origin reduce the impact strength. Regarding the strength of the products, surface smears and micro cracks are caused by a misadjusted (meaning a too high) blank mould speed, the presence of abrasion particles (in µm size) as well as by sticking glass [1]. Another important fact is the heat transport and the heat transmission while forming. To avoid damages on the inner surface of the glass container, temperature variations between base and coating material as well as in the contact area between glass and plunger material need to be evaluated.

Hot glass sticks to metal, if the metal is heated to or above the sticking temperature of glass [2]. Parameters influencing the complex process of sticking are temperature, viscosity, surface tension, specific heat and thermal conductivity of the mould material. Thin but stable oxide layers and the use of lubricant building up on the plunger surface reduce the tendency towards sticking, because the direct contact of glass with the mould surface can be prevented.

The topic of sticking is differently discussed among glass specialists. Stuck ware occurs, if the temperature characteristic of one type of ware at the contact surface between glass and mould is exceeded. In this case the heat to be withdrawn from the glass can not be removed away fast enough.

This effect can be described as follows: At the glass-mould contact of two different mould materials of identical specific heat an increased sticking occurs in that mould where the thermal conductivity is lower. Further-

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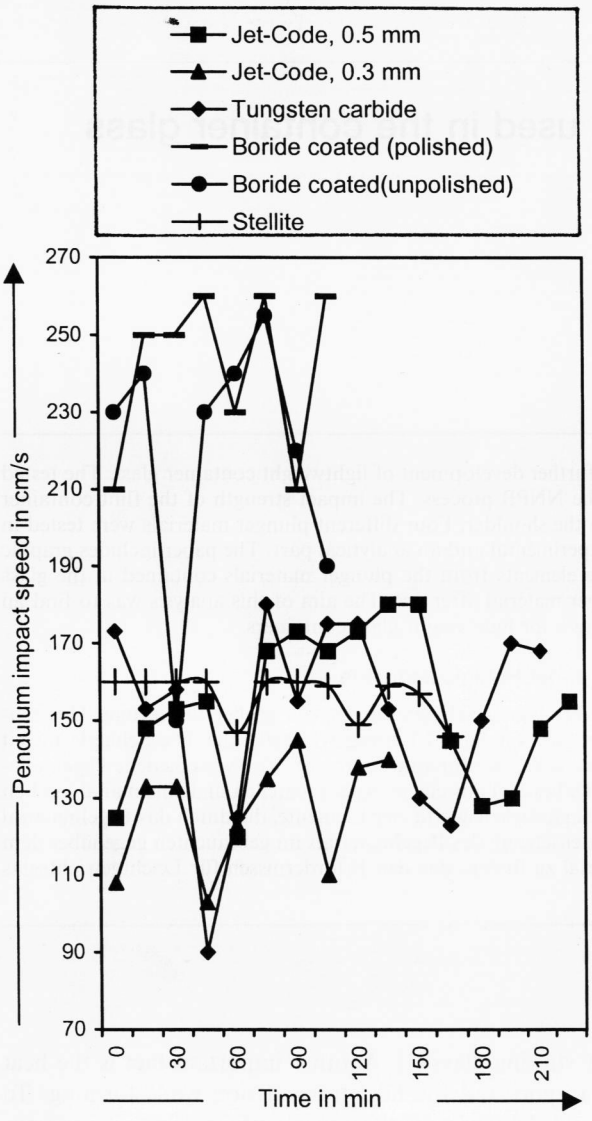

Figure 1. Experimental averaged data obtained from impact strength analysis from glass containers produced with four different plunger materials. The plunger materials are different in thickness of coating and surface treatment. They were tested in contact with glass during machine operation at working temperature.

more, the chemical composition of the mould material has substantially less or no influence. However, the condition of the glass (e.g. viscosity) entering the mould has a great influence on the sticking behaviour [3].

Publications in the past have described the sticking temperature in different ways. One reason for this is that there are different methods of testing used to investigate the sticking temperature. The present paper uses the initial plunger temperature, which causes sticking, as definition for sticking.

2. Experimental

The experimental setup of the test run was structured in two parts. In the first part, plungers of various materials were used producing articles for several hours under constant temperature. In the second part, an increasing of temperature by an hourly reduction of the cooling air was applied until sticking between glass and plunger occurred. For documentation and analysis purpose impact strength tests were performed on containers produced during both parts of the experiment.

In figure 1 the results of the impact strength tests are compiled. In the analytical part of the evaluation chemical elements from the top of the plunger were examined by X-ray microscopy (i.e. EDAX = energy dispersive analysis X-ray) comparing the materials before and after use in the IS machine. Figures 2 and 3 inform about the change in chemical composition of the plunger materials before and after use. Figure 4 shows an additional X-ray analysis, where the chemical elements of the defect origins found in the glass of the produced containers were analysed.

2.1 Method of testing

2.1.1 In general

Four different plunger materials were examined, two of them showed significant differences in surface properties and thickness of coating:

- stellite,
- jet code – coating thickness 0.3 and 0.5 mm,
- tungsten carbide,
- boron coating – polished and unpolished.

The plungers, coated with the above-named materials, were inserted into a 12 section Emhart machine. This machine is a double-gob machine with electronic control and air drive. It is in operation to produce 1 l nonreturnable flint glass water bottles with the narrow neck press and blow (NNPB) process. The analysis of the different plunger materials was performed on this article.

2.1.2 Use of the plunger materials in the production process

In order to keep all production parameters constant during production, section no. 2 of a 12 section AIS (Advanced-Individual-Selection) machine was chosen. In this section all plungers of different materials were tested.

Every plunger tested stayed in the selected section the exact same amount of time. Afterwards the plungers were in use till they stuck. The increase of temperature which leads to the sticking is an effect of angle variations at the cooling air supply area of the IS machine. The adjustment of this angle has an influence on the air throughput, which is necessary for the cooling of the inside plunger surface.

The examination of the articles produced with different plunger materials was performed with an impact strength test. As test location the upper contact area in

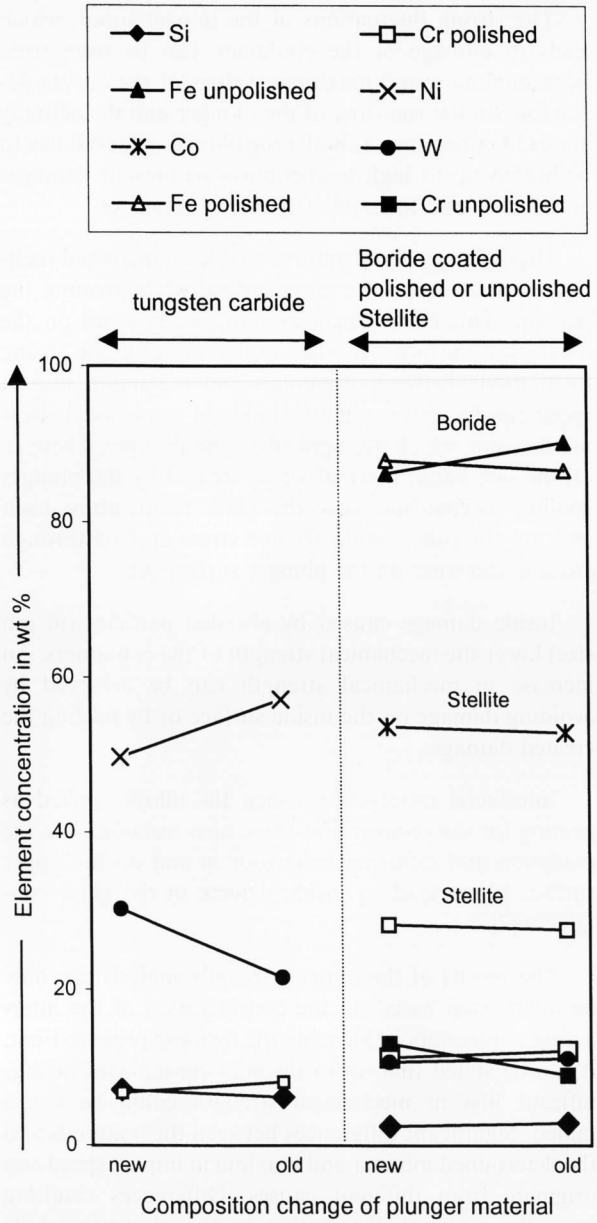

Figure 2. Variation of chemical composition of plunger materials before and after use. Averages of experimental data obtained by X-ray analysis (EDAX) on three different locations on the plunger top after sticking temperature had been achieved.

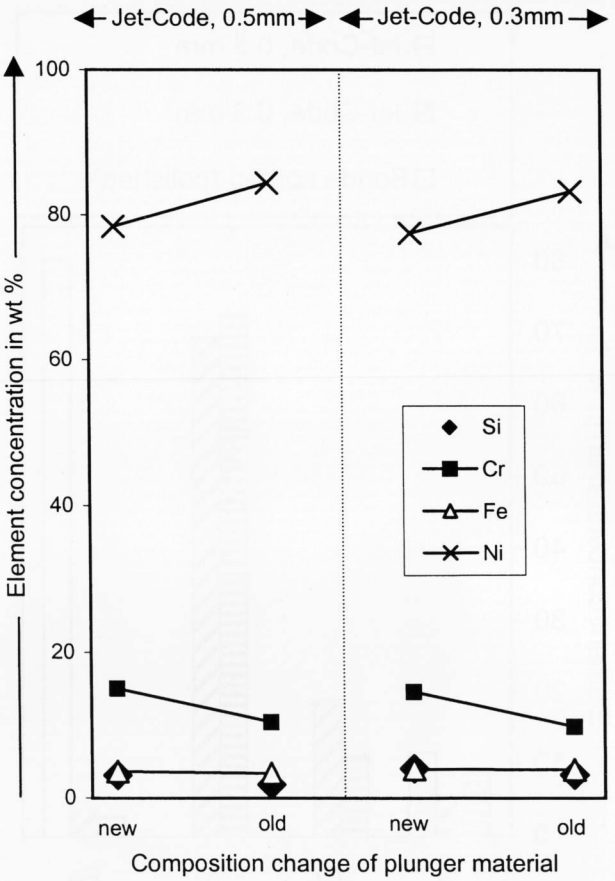

Figure 3. Two additional materials with different coating thickness applying the same analysis procedure as in figure 2.

2.2 Temperature measurements during the production process

The plunger surface is normally inaccessible for temperature measurements. The measurement on the plunger surface during continuous production with a hand pyrometer did not give reproducible results. But it is commonly known that the plunger has to withstand a higher thermal stress than the mould itself [5].

the shoulder was chosen, tested on a device (the Impact Tester) especially developed for this matter by AGR International Inc., Butler, PA (USA). With this tool it is possible to adjust the impact speed and the initial angle up to a maximum of 135° without gradation.

To determine the impact strength in the upper contact area, the article was tested at three different locations at that height. In order to avoid hitting the same location for three times, a rotation of 120° was made after each impact. The test construction has a pendulum, with an initial impact speed of 20 cm/s on the article. The speed was graduated in steps of 10 cm/s until breakage occurred [4].

3. Compilation of the test run

The following special program was prepared for the experiments:

- the use of different plunger materials under production conditions on one individual section in the daily industrial flow;
- article samples taken at a fixed point on the belt behind the annealing lehr;
- a standard 20 min break period between the sampling rounds;
- effects of different imbedded materials on the container strength were investigated with an impact strength tester.

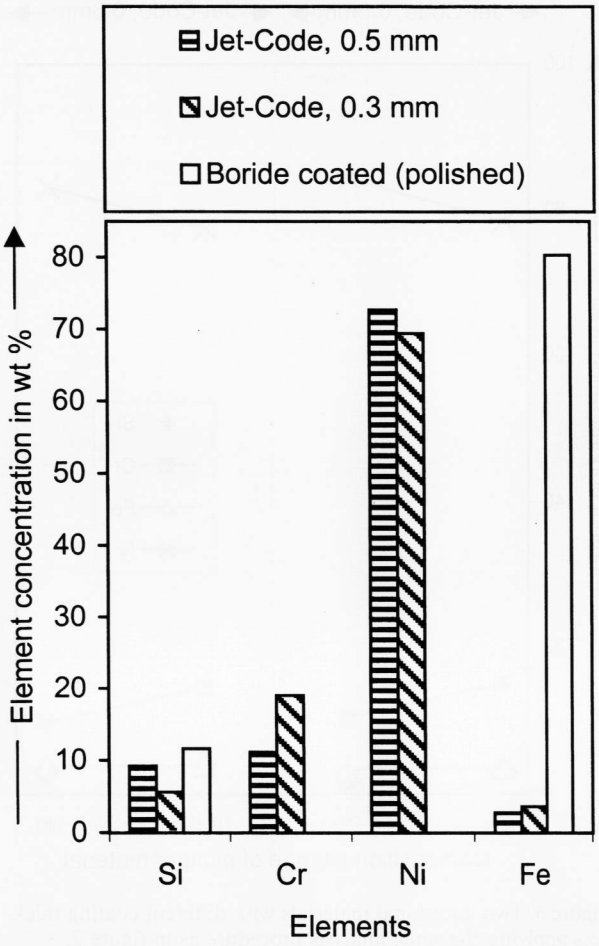

Figure 4. Chemical composition of defect origins, measured with X-ray analysis (EDAX).

The analytical part of the experiments was structured as follows:

- selection of samples for a stereo-microscopic examination;
- articles which show abrasion were collected and examined;
- EDAX examination of the chemical composition of the defects on the inside glass surface and an examination of the new unused plunger materials in comparison with the plungers removed from the machine at the end of the run time.

4. Experimental results

An average has been calculated in figure 1:

- from four measurement results per reference point for the jet code and tungsten carbide material;
- from two measurement results per reference point for the boron material;
- and from six measurement results per reference point for the stellite plungers.

The strong fluctuations of the impact speed, which leads to damage of the container, can be recognized from minimum and maximum values of the curves depending on the run time of the plunger and the actually applied temperature. Initially the plunger material has to be heated up to high temperatures to prevent damages in the glass and to enable the cure of damages.

High plunger temperatures enable an increased melting temperature on the glass surface while forming the parison. This effect can also cure the damages on the inner glass surface. Another explanation for the strong fluctuations between minimum and maximum impact speed can be seen in the two kinds of mechanical stress mechanisms which are applied to the plunger. There is, on the one hand, thermal stress created by the plunger cooling mechanisms and the glass temperature itself and, on the other hand, frictive stress applied through erosion and wear on the plunger surface [6].

Inside damage caused by abraded particles (in µm size) lower the mechanical strength of the containers. An increase in mechanical strength can be achieved by avoiding damage on the inside surface or by healing the created damages.

Interfacial processes between the alloys applied as coating for the plunger and glass, also reactions like the oxidation and diffusion behaviour in and on the upper surface layers lead to inside defects in the glass containers [7].

The results of the impact strength analysis can only be interpreted based on the consideration of the interacting parameters influencing the forming process. First, it can be stated that up to the sticking moment no significant loss in mechanical strength could be determined. Significant differences between the materials and the determined minima and maxima in impact speed can originate from different causes. Differences resulting from the material distribution in the plunger and its cooling system may serve as an example. In this case differing local temperatures on the plunger surface are created. The overall increase in temperature could lead to a higher thermal stress in the plunger itself, where the overall life of the material has to be considered. On the other hand, an increased inner surface temperature of the parison contributes to an improved healing of defects. Finally another element has to be seen in the statistical character of the complete investigation.

In conclusion an ideal plunger should therefore incorporate the following properties:

- increased thermal stress resistance especially for temperature variation,
- corrosion resistance,
- adapted design regarding plunger wall thickness distribution and cooling mechanisms,
- optimized and stabilized process technology regarding the general cooling,

– for an optimized impact strength of the containers it should be aimed for the highest possible plunger temperature in order to support the out-curing processes.

5. Coatings for pressing tools

In the area of industrial production expectations in respect of quality and performance are increasing. In order to maintain competitiveness, more price-efficient products have to be produced with a minimum amount of production loss due to defective containers. The use of metal powder on the basis of nickel-chromium-boron-silicon or nickel-boron-silicon on newly armed or repaired moulds and plungers has been established in the container glass industry. Economic efficiency increases with improvements in quality and higher productivity per mould and machine as downtimes are reduced. In this paper EDAX analysis provides useful knowledge about the components of the contact material down to a volume information of 1 μm^3. This analysis has been applied to various locations on the plunger surface. For this investigation the top of the plunger was cut off slightly lower than the head to shaft transition.

The average displayed in figure 2 has been calculated from three reference values at the measured locations (new and old). The plungers named "old" except the boride-coated unpolished plunger ran in the section until achieving the sticking temperature applying an hourly increase of temperature. Elements like oxygen, carbon, and boron cannot be determined by EDAX analysis due to their low atomic weight. It appears (figure 2) that the plunger with stellite material is not influenced by high temperatures. The mass percentage of the different chemical components in the alloy are only slightly changing from new to old. No optical defects were visible in the glass containers when production ran with the stellite material. For this reason no EDAX analysis was performed. Also plungers with tungsten carbide showed during stereo-microscopic analysis no visible defects on the containers produced. In figure 4 all inside defect-causing materials and their elements are displayed.

An evaluation of the properties of an alloy with the elements cobalt, chromium, tungsten and carbon at room temperatures supports the interpretation of a high-temperature resistance and corrosion resistance of this alloy. Furthermore the mechanical property of hardness which protects the material from abrasive wear plays a substantial role. In figure 2 it is visible that the tungsten content in the material decreases from "new" to "old". This can be interpreted as abrasion of coating during the use at high temperatures. This explanation can be supported with the observation of an increase in nickel in the material from new to old. The basic material in this plunger is steel which may explain the increase of iron. Protective coatings containing chromium and nickel protect the iron body from the influence of air and humidity and avoid its corrosion. The observed nickel content in the alloy is higher than the content of chromium. During the EDAX analysis of the top of the plunger (figure 2) a higher content of nickel than chromium could be determined. According to [7] it can be suspected that the glass surface was mostly in contact with nickel due to the strong increase of nickel in the plunger surface.

In figures 3 and 4 it must be outlined that nickel, chromium and iron did not enter the glass through diffusion, but abraded in form of metal particle at the contact location between glass and metal. Looking at the jet code material with 0.3 and 0.5 mm coating a greater diffusion behaviour of nickel in respect to iron and chromium from the alloy layer on the plunger tip into the glass could be detected. This information can be taken from the particle abrasion shown in figure 4.

The basic material of a boride-coated plunger is a special alloy based on chromium and tungsten. In comparison with figures 2 and 4 it is stated in [7] that due to a strong increase of iron at the surface of the steel plunger, the contact of the glass melt only consists of a contact with the basic material iron. In this case the high content of iron particles may originate from metal particles of the basic material of the plunger.

During testing on a continuously operated glass forming machine the stellite plunger showed the best performance and properties. Even at high temperatures impact strengths of 160 cm/s were obtained without any container breakage.

Examinations with the stereo microscope while producing showed no inside defects on the surface of the articles produced with this plunger material. The EDAX analysis of the plunger top (figure 2) shows that also at high temperatures probably no material weaknesses occurred, because the alloy components did not vary in mass percentage from new to old.

6. Conclusion

The effect of the different glass-production influencing parameters in a continuously operating forming machine makes it necessary to use a plunger which is capable of compensating the variations of the production process. For a continuous lightweighting of glass containers the need of simultaneous increase of the impact strength has been demonstrated by the results achieved and discussed in this paper. This information allows the selection of optimum material properties for an ideal plunger.

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7. References

[1] Döll, W.: Glas im Kontakt mit Formgebungswerkstoffen für die Hohlglasproduktion. Reported at Technical Committee IV "Glass machine Technology and Forming" of the German Society of Glass Technology (DGG) in Würzburg (Germany) on 5 March 1991.

[2] Giegerich, W.; Trier, W.: Glasmaschinen, Aufbau und Betrieb der Maschinen zur Formgebung des heißen Glases. Berlin et al.: Springer, 1964. p. 102.

[3] Hengstenberg, O.; Müller, H.: Sonderstähle als Werkstoff für Glasformvorrichtung. In: Ueber Glasformen aus Sonderstahl, sowie den Wärmefluß in solchen, und in Glasformen überhaupt. 1. T. Fachausschußber. Dtsch. Glastechn. Ges. no. 31, 1934. p. 135–139.

[4] Stahlhut, P.: Untersuchungen über den Einsatz von Siliciumcarbid als Formstoff in der Hohlglasproduktion. Univ. Duisburg, diploma thesis 1991/92.

[5] Seidel, O.: Beitrag zur Gestaltung von Glaspreßwerkzeugen unter besonderer Berücksichtigung thermischer Aspekte. Bergakademie Freiberg, diss. 1992.

[6] Eschnauer, H. R.; Knotek, O.; Steine, T.: Grenzflächenvorgänge zwischen NiCrBSi-Legierungen und Glas. Glastechn. Ber. **43** (1970) no. 2, p. 53–56.

[7] Baranyai, A.: Untersuchungen von Festkörperoberflächen im Hinblick auf die Adhäsion von oxidischen Glasschmelzen. Univ. Freiburg, diploma thesis 1993.

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