5-31-1991

Analysis of the influence of natural wear and tear in gates and runners on the filling of a balanced multi-cavity injection mold

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Recommended Citation

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ABSTRACT

Analysis of the influence of natural wear and tear in gates and runners on the filling of a balanced multi-cavity Injection Mold

Ranga Reddy V. Adavelly, Master of Science, 1991

Thesis directed by: Dr. Keith O'Brien, Professor of Mechanical Engineering

Design of injection molds is outmost important in the manufacture of parts. Its components runners and gates significantly influence the mold filling. Using a simulation package for injection molding a balanced multi-cavity mold was designed. Wear in the gates of runner was simulated by varying the cross-sectional area of the components. Influence of wear of tear in gates of runners on mold filling was measured in terms of flow rate of time of fill. Detailed analysis is done on four different models using four different materials Polycarbonate, Polypropylene, Nylon6 and Polybutylene terephthalate. Graphical display of result is presented and analyzed in terms of deviation in time of fill and flow rate from their original values. Remedies suggested for reducing the affects of wear and tear and replacement of the equipment.

APPROVAL SHEET

Title of Thesis:

ANALYSIS OF THE INFLUENCE OF NATURAL WEAR AND TEAR IN GATES AND RUNNERS ON THE FILLING OF A BALANCED MULTI-CAVITY INJECTION MOLD

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ANALYSIS OF THE INFLUENCE OF NATURAL WEAR AND TEAR IN GATES AND RUNNERS ON THE FILLING OF A BALANCED MULTI-CAVITY INJECTION MOLD

By

RANGA REDDY V. ADAVELLY

Thesis submitted to the faculty of the Graduate School of New Jersey Institute of Technology in the partial fulfillment of the requirements for the degree of Master of Science in Manufacturing Engineering.

1991

To My Parents

Acknowledgements

I take this oppurtunity to express my deep gratitude to Dr. Keith O'Brien, Professor, Mechanical Engineering Department of N.J.I.T for his valuable guidance and help throughout the course of this work. It was his immaculate advice, which led my work to the set mark of culmination.

I am also very thankful to Dr. Nouri Levy and Dr. Rong Chen for spending their precious time to review my work and to provide constructive suggestions for enhancing my work.

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CHAPTER I

INJECTION MOLDING

1.1 General comments

Injection molding is an important processing technique for converting thermoplastic and thermosetting materials into final products. Injection molding produces parts in large volume at high production rates and at low cost. The parts require little or no finishing and many different surface finishes are available. The same article can be molded with different materials on the same equipment. Close tolerances can be maintained. Parts can be molded from a combination of plastics and fillers, eg,glass,asbestos,talc and carbon.

The process permits the manufacture of very small parts which are impossible to fabricate in quantity by other methods. Scrap losses are minimal as runners, gates and rejects can be reground and reused. Since energy costs are low, this process is the most economical way to fabricate many shapes.

Injection molding is a cyclical process which encompasses the following steps : Heating and melting the process material, mixing and homogenizing the now liquid material; injecting the melt into the mold cavity; and ejecting the finished part from the mold. Thus, the significant elements of an injection molding machine become 1) the way in which the melt is plasticized and forced into the mold (injection molding), 2) the system for opening the mold and closing it under pressure (clamping unit), 3) the type of mold used, 4) the machine controls [1].

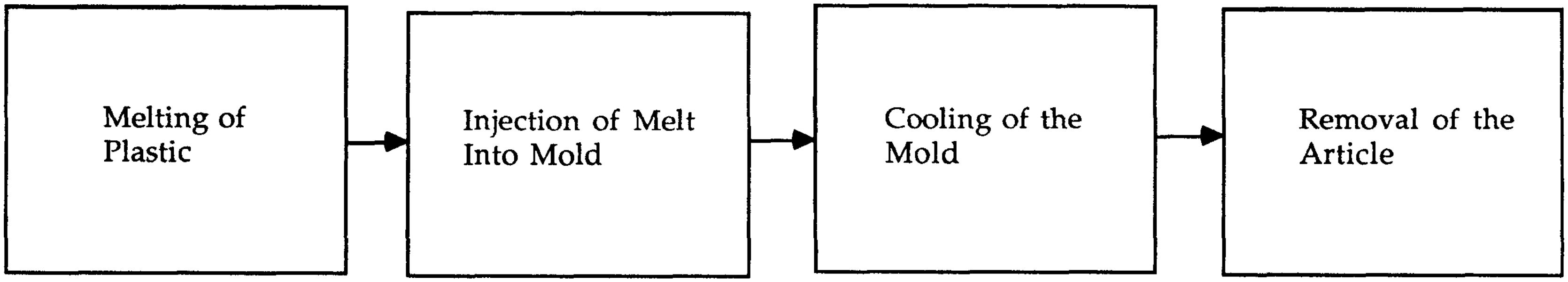


Fig 1.1: Stages in Injection Molding

1.2 Types of machines

Types of injection molding machines used include plunger and screw types. In the plunger type injection molding machine plastic is pushed forward by a plunger through a heated region. Because the high viscosity of melt prevents any significant convective heat transfer it is necessary to spread the molten material in a thin layer to contact the heated surfaces. The torpedo shown in figure 1.1 diverts the material so that it moves through a thin annular region. After melting, the material converges and flows through a nozzle which delivers to the mold. Reciprocating screw machine is explained in the next section.

1.2.1 Clamping units

Hydraulic clamps and toggle clamps are used for keeping the molds closed during injection. Mechanical hydraulic clamps that combine features of both are also used. Most clamps in use are horizontal, with the injection taking place through the center of the stationary platen. But for special jobs vertical clamp presses are available.

1.2.2 Molds

The heart of the molding process is the mold. It gives shape to the part, it vents the entrapped air, cools the part and ejects or strips the parts without marks or damage.

1.2.3 Machine controls

Controls are mainly used to monitor and set up corrective action for the different processing variables like temperature, pressure, time and etc. Mostly PID controls are in use for the present machines.

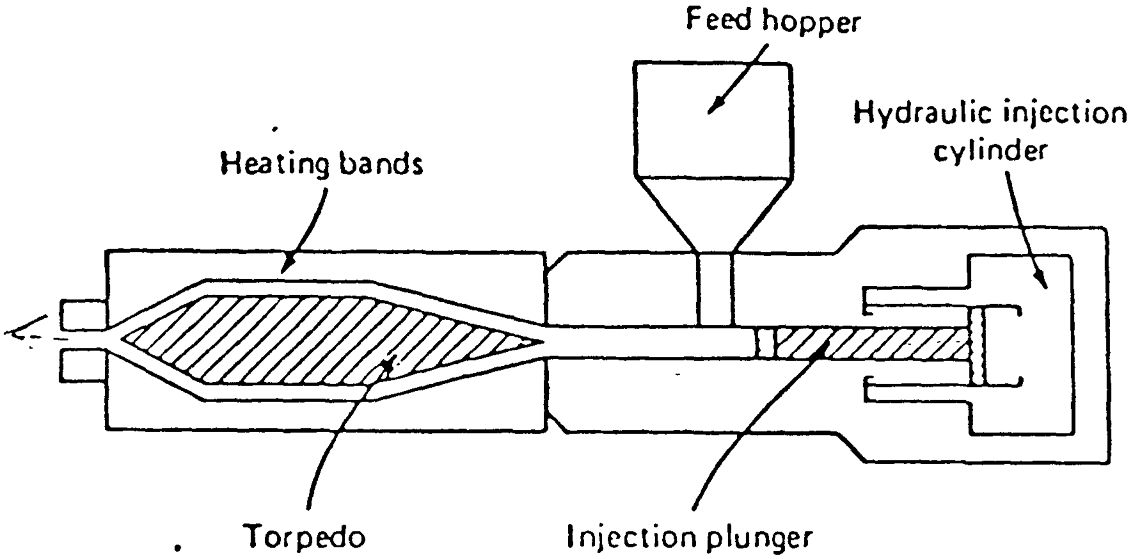


Fig. 1.2 Plunger type Injection molding

In more common use currently is the reciprocating screw type. It has faster cycles,lower melting temperatures,and better mixing of the materials. Pressure drop is lower and the melt is more homogeneous.

1.3 Molding process in reciprocating screw machines

As shown in figure 1.2 plastic granules are fed into the hopper and through an opening in the injection cylinder where they are carried forward by the rotating screw [2]. Simultaneously, the mold is closed and enough pressure is applied to keep the mold closed during the injection cycle. The material is heated, until it is in the molten state, and then it is injected through a nozzle into the mold cavity. During the filling stage, the molten polymer is introduced into mold cavity through the delivery system. The delivery system consists of the nozzle region, the sprue, the runner system, and the gate. The sprue is usually a short diverging conical channel which is the main pathway to the mold connecting the nozzle and the runner system. The function of the runner system is to deliver the hot melt to the cavity with minimum pressure drop [3].

Relatively slow cooling is also important to avoid premature solidification. The gate controls the flow of melt into the cavity, which depends on its shape and location. A narrow gate is normally specified in order to facilitate the demolding process. The injection pressure is maintained for a predetermined length of a time. Injection pressure is maintained to fill the mold as quickly as possible and to mold a part free from marks, welds and other defects. A valve at the tip of screw prevents material from leaking into the screw flights during injection. It opens when the screw is turning and melting material, permitting the plastic to flow in front of it to force the screw back.

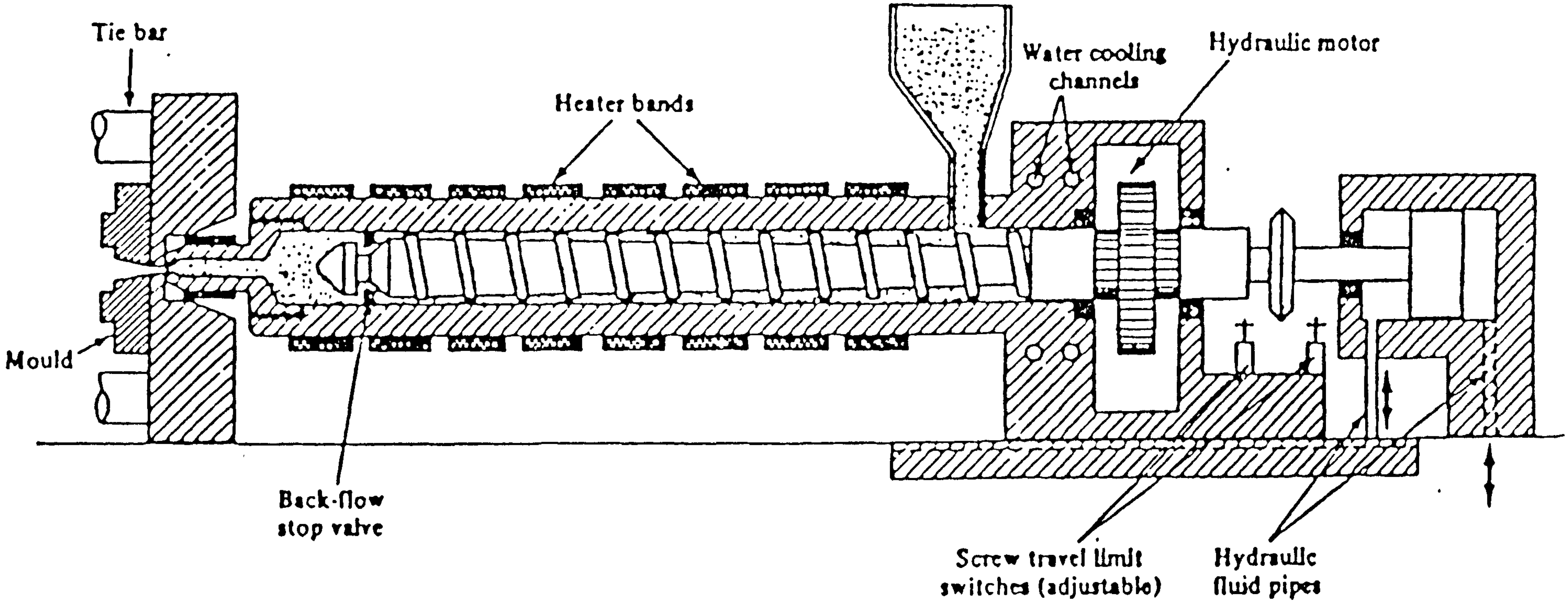


Fig. 1.3 Reciprocating screw Injection molding machine

Since plastic is injected into the mold at high pressure, a large clamping force is required in all injection molding machines. In order to keep the mold closed against the injection pressure, either mechanical or hydraulic clamps are used. As injection pressures are high even a small part requires a big clamp to hold it closed.

Injection molding machines are rated in terms of the clamping force and injection capacity of molten plastic. These clamps are large and expensive. They have to open and close rapidly and maintain stiffness. Two techniques are used for generating the clamp force. A hydraulic ram is simple and is used for very large machines. Small machines use a mechanical toggle. The mechanical toggle mechanism allows high forces when the mold is nearly closed and rapid motion capability when the mold is open. In recent years electromechanically actuated injection molding machines using servomotors, to control screw rotation, injection cycle and mold draining motions have been developed [4]. These are quicker and cleaner than hydraulically actuated machines.

Water cooled molds cause the plastic to cool quickly. As the material cools, it becomes more viscous and solidifies to the point where injection pressure is no longer needed. The mold is opened and the part is ejected from the movable half of the mold usually by air pressure or spring loaded ejector pins. The mold is then closed to begin another cycle.

The mold temperature must be maintained below the softening point of the material being molded. It must be high enough to prevent shrinkage of the plastic, due to hardening of the outside of the mass too quickly. Mold temperatures run from 32^{o} to 300^{o} F . Because the plastic is extremely viscous, typical injection pressures range from 10,000 to 40,000 psi depending on the molding compound.

Efficient reciprocating screw injection molding requires that the screw expends the maximum of work by operating at the highest possible screw speed and back pressure, while cylinder temperature is held as low possible. Thus, the screw contributes significantly to the heating of the melt. Specific operating conditions depend to a large degree on the resin used.

1.4 The plasticating screw

The screws used in the injection molding machines may be classified by their distinct zones. Although the screws have uniform outside diameters the flight depth varies along their length. The three zones are called the feed, compression and metering zones. Flight depth is deepest in the feed zone nearest to hopper to provide ample space for the material granules to be picked up in the initial flights.

The flight depth diminishes in the compression or transition zone to compensate for the increased density and to increase the force on the material and thereby provide for more shear action to develop heat within the melt. The final metering zone has a small uniform flight depth to complete mixing and to pump melt into the injection chamber ahead of the screw.

1.5 Screw drives

Standard injection molding machines employ either electrically or hydraulically driven screws. Both systems are accepted by the industry. Selection of the proper drive system for a reciprocating screw machine involves an understanding of the melt flow characteristics of thermoplastics.

All injection molding machines make use of electrical heaters to aid in the plastification of the material being processed. The most common system uses mica heater bands of high wattage. Several of these heaters are used per zone on the injection cylinder, the number depending on the size of the machine.

The principal variables that must be controlled are as follows:

1. Temperature of the mold
2. Temperature of the melt.
3. Mold closing time.
4. Mold clamping force.
5. Mold open time.

1.6 Molding Cycle

The cycle time is dictated by part thickness. Typically it takes few seconds for injection. Pressure is then held for several seconds during which the part cools so that more plastic can be packed into the mold to compensate for thermal contraction. The total injection molding cycle time can be from a few seconds to several minutes depending on the thickness. Cooling time is often the longest fraction of the cycle time [5].

The molding cycle is made up of several parts as shown in figure 1.4. The major elements of cycle are 1) screw forward time, 2) hold time, 3)mold open time. Screw forward time involves injection plus the time that the screw is held forward by hydraulic pressure. During hold time, the screw rotates and retracts, and the moldings cool sufficiently to be ejected when the mold opens.

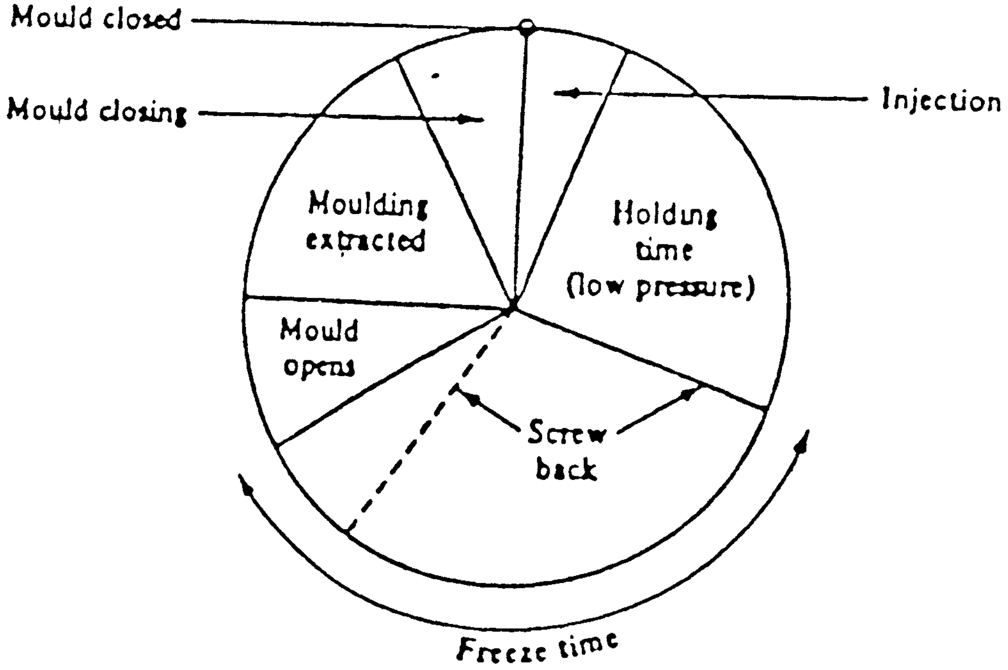


Fig. 1.4 Molding cycle

Time, pressure and temperature are the basic variables that must be controlled given the poor thermal conductivity of the thermoplastics. The temperature of the plastic is a critical variable since viscosity is controlled by temperature. Mold temperature is controlled by circulating fluid and a means of heating and cooling the fluid. The quality of the molded product is highly dependent on the ability to adjust these control settings.

1.7 Injection Molding Process Control

In the field of polymer processing, polymer feedstocks are converted into useful products. The process parameters which influence these processes include temperature, speed, pressure, thickness and position. To make a successful product it is necessary to control the above mentioned process parameters. The following are control actions used in the plastic processing.

Injection molding is cyclic, dynamic and unsteady state in nature. To control the process conventional PI (proportional + integral), and PID (proportional+integral+derivative) controllers are used as shown in Fig. 1.5. More advanced control schemes such as self tuning control, optimal control, and statistical process control are also applied. The controlled variables have been categorized into all phase control, phase dependent control, and cycle to cycle control. All phase control includes the variables that must be monitored and controlled all times. Phase dependent control takes in specific phases. In cycle to cycle control previous data are used to predict future trends and corrections to be made.

In all phase control, variables are controlled throughout the molding cycle. In this melt temperature which is a fundamental variable is controlled.

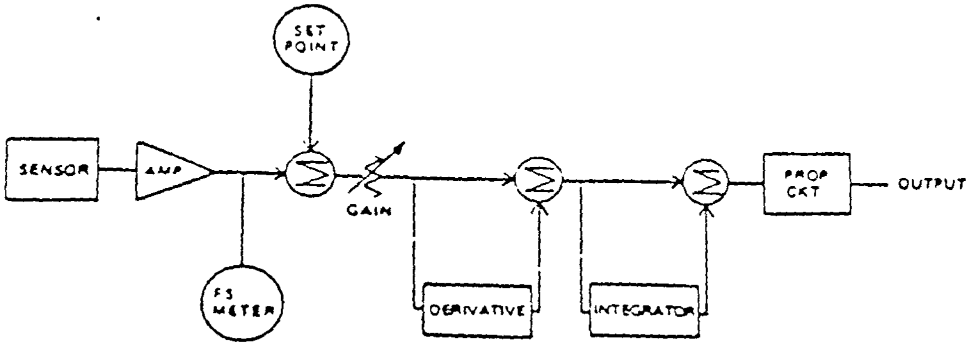


Fig. 1.5 PID controller

(Courtesy of West Division, Gulton Industries, Inc.)

In phase dependent control, different phases like the plastication phase, the injection phase, or the holding phase of the molding process are controlled. In plastication phase melt temperature is the most important to variable to be controlled. Injection velocity, viscosity and peak cavity pressure controls are important during filling.

During the holding phase the key variables to be controlled are hold pressure, specific volume, and melt temperature. It is also important to control the filling phase to hold phase to ensure consistency of part weight.

In cycle to cycle control, corrective actions are taken in the subsequent cycle based on the information from the preceding cycles. Shot size control and statistical process control fall in this category.

1.8 Advantages of Injection Molding [6]

1. Parts can be produced at high production rates.
2. Large volume production is possible.
3. Relatively low labor cost per unit is obtainable.
4. Process is highly susceptible to automation.
5. Parts require little or no finishing.
6. Many different surfaces, colors, and finishes are available.
7. Good decoration is possible.
8. For many shapes this process is the most economical way to fabricate.
9. Minimal scrap loss results as runners, gates,and rejects can be reground and reused.
10. Close dimensional tolerances can be maintained.

11. Same item can be molded in different materials, with out changing the machine or mold in some cases.
12. Process permits the manufacture of very small parts which are almost impossible to fabricate in quantities by other methods.
13. Parts can be molded with metallic and nonmetallic inserts.
14. Parts can be molded in a combination of plastic and such fillers as glass, asbestos, talc,and carbon.
15. The inherent properties of the material give many advantages such as high strength-weight rates, corrosion resistance, strength, and clarity.

1.9 Disadvantages and Problems of Injection Molding

1. The plastic industry has very low profit margin.
2 Three shift operations are often necessary to compete.
3. Mold costs are high.
4. Molding machinery and auxiliary equipment costs are high.
5. Process control may be poor.
6. Machinery is not consistent in operation, and controls do not directly measure what is supposed to be controlled.
7. The possibility of poor workmanship is often present.
8. Quality is often difficult to determine immediately.
9. Lack of knowledge about the fundamentals of the process causes problems.
10. Lack of knowledge about the long term properties of the materials may result in long term failures.
11. Plastic cannot be made so that each pellet is same. One must deal with averages of molecular weights and molecular configurations which vary

not only from pellet to pellet but on larger scale from batch to batch. This causes an unsteady and varying operational state.

12. To derive quantative equations for flow and other properties needed in injection molding, one must know viscosity , temperature and pressure. In a mold they are continually changing and not measurable. The assumptions made may lead at best to some very questionable results when applied in practice.

CHAPTER II

INJECTION MOLDS

2.1 Introduction:

The mold is the most important part of the injection molding machine. It is often very complex with intricate shapes and excellent surface finishes. It has cooling channels arranged to ensure uniform solidification of the molded part. The cavity is connected to the runner through a gate. Some molds have multi-cavities for the part to be molded. The mold must be designed so that the part can be removed easily. Most molds consist of two main plates which separate to release the part. The part release is sometimes assisted by ejector pins which push the molded part out of the mold. Some molds are made of several plates.

Three general types of molds are used and these may be subdivided into several classes. They are compression molds, transfer molds and injection molds [7]. The injection mold is essentially a closed mold. After the application of pressure to close the mold and hold it tightly clamped against injection pressure, the molten plastic material is forced into the closed cavity by a source of pressure other than that which caused the mold to close. The material passes through sprue, runners and gates into the cavity as shown in the figure 2.1. The point at which the core and cavity separate or move apart when the mold is opened is called the parting line.

Injection molds are used for molding either thermosetting or thermoplastic materials. In the case of thermosetting material the mold is run hot, i.e., hotter than the plastic material that goes into the mold. In the case of thermoplastic material the mold is run cold, i.e., colder than the plastic material that goes into the mold.

2.2 Types of molds

1. Two plate
2. Three plate
3. Loose details
4. Horizontal or Angular coring
5. Automatic unscrewing
6. Rising cam or ejector angular movement
7. Ejection on nozzle side of mold

2.2.1 Two plate mold

Mold cavities are assembled to one plate and forces to the other plate with central sprue bushing assembled into the stationary half of the mold, permitting a direct runner system to multiple-cavity molds or direct center gating to individual-cavity molds. The moving half of the mold normally contains the forces and the ejector mechanism, and in most designs the runner systems [8]. This is the basic design for injection molding and all other designs are developed from this fundamental design which is illustrated in figure 2.1.

2.2.2 Three plate molds

The introduction of another intermediate and movable plate, which normally contains the cavities for multiple-cavity molds, permits center or offset gating of each cavity from the runner system which connects to the central sprue bushing. A typical three plate mold is shown in fig. 2.2.

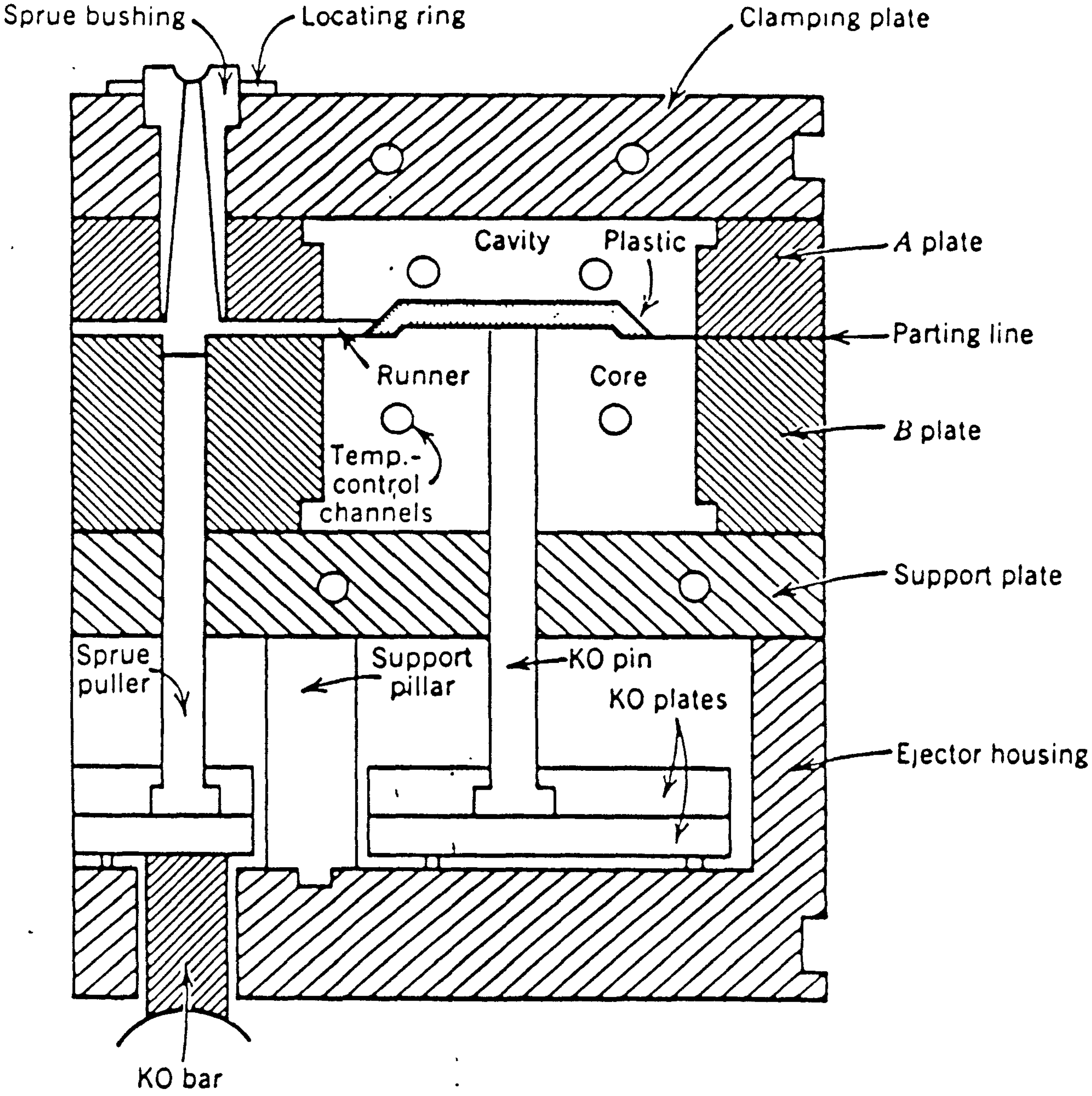
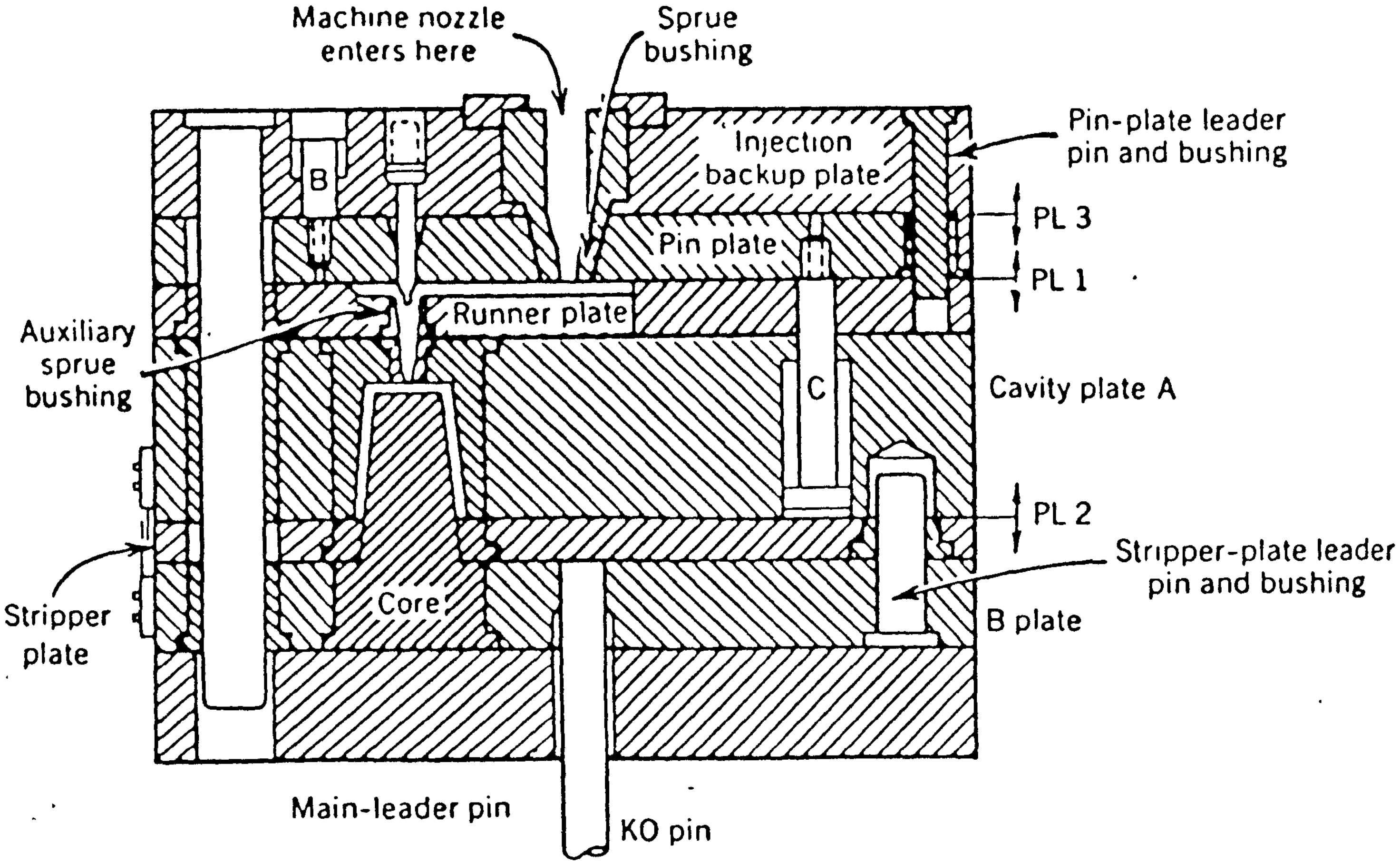


Fig. 2.1 Basic two plate Injection mold



(a)

Fig. 2.2 Basic three plate Injection mold

2.2.3 Loose details

Threads, inserts, or coring which cannot be produced by normal operation of the press are often processed by separate mold details which are ejected with the part and removed by hand or with a disassembly fixture after cycling. This practice is often used for experimental or small production requirements to minimize the more costly semiautomatic mold details.

2.2.4 Horizontal or angular coring

This practice permits the movement or coring of mold sections which cannot be actuated by the press, through the use of angular cam pins that permit secondary lateral or angular movement of the mold members. This design is used for intricate product production requirements.

2.2.5 Automatic unscrewing

Internal or external threads on product designs require large volume and low production costs, and are processed from molds that incorporate threaded cores or bushings actuated by a gear and rack mechanism, and moved by a long double-acting cylinder sequentially timed within the molding cycle.

2.2.6 Rising cam or ejector angular movement

This design is used to mold undercuts on the interior of parts. Angular movement of the core through the ejection travel permits release of the metal core from the part.

2.2.7 Ejection on nozzle side of mold

This design is used when it is necessary to having gating and ejection on the nozzle, or fixed half of the mold.

The function of a mold is to receive molten plastic material ranging in temperature from 350 to 750 ^{O} C at pressures between 5000 and 20000 psi. In the injection process the plastic comes from the heated nozzle and passes through the sprue into the feed lines (runners) and thence via a gate to the cavity . Cavity temperature is 32 to 350 ^{O} F.

A flow in the mold may be described as the increment of pressure drop that is responsible for moving a segment of the flow forward and is resisted by the shear stresses acting on both faces. Computer solutions of the governing equations of heat transfer and momentum can be conducted. The length of the path that the material flows from machine nozzle to the extreme position of a cavity will govern to a large degree the mold temperature. Higher mold temperatures will give stronger weld lines, lower stress levels, glossier appearance and deeper sinks. Molding stresses are concentrated around gates, inside sharp corners and weld lines.

2.3 Mold Components

A mold consists of sprue, runners, gates and cavities. The filling of the cavity depends mainly on the runners which transfer the material and gates which regulate the flow. The mold is connected to the injection unit through nozzle.

2.4 Nozzle

Usually have a spherical nose. The mating spherical recess on the sprue bushing in the mold is usually made 1/32 in. larger than the radius of the nozzle in order to reduce leakage by ensuring positive seating of the two spherical surfaces at the region of the orifice and to reduce heat loss from the nozzle to the mold.

2.5 Sprues

This is the main feed channel to the runner, so should be adequate in diameter at both ends of the taper. The large end should be as big as, or larger than, the diameter of the main runner. The small end of the taper should not be smaller than the orifice of the nozzle.

The sprue is normally located in the mold half not having an ejector mechanism. A sprue puller is provided to separate the sprue from the nozzle as the mold opens. A pin is attached to the ejector plate of the mold and pushes the sprue from the sprue puller during the ejection stroke. Three styles of sprue pullers are groove, reverse taper and undercut. The reversed taper method is preferred since the sprue is completely free upon ejection and does not require an operator to remove it.

2.6 Gates

The gate is the connecting link between the runner and cavity. It acts as a throttling and shutoff valve for the cavity by restricting the flow during the filling of the cavity and sealing off the cavity after it has been filled. Gates are usually round or rectangular. A rectangular gate is preferred since it independently controls the flow rate through the gate and gate seal off time. The thickness of a rectangular gate determines the time for gate to seal, whereas the width can be adjusted to increase or reduce the volumetric flow rate through the gate with out affecting the seal time. With circular gates, a change in radius changes both the gate seal time and flow rate. It is rather difficult to mold plastic parts successfully if the material is not delivered to the mold cavities as fast and efficiently as possible.

The factors that determine size, quantity, shape, and placement of gates, sprues, and runners are :

1. Material to be molded
2. Appearance criteria of part
3. Size and cross sectional area of part
4. Type of mold
5. Production quantity

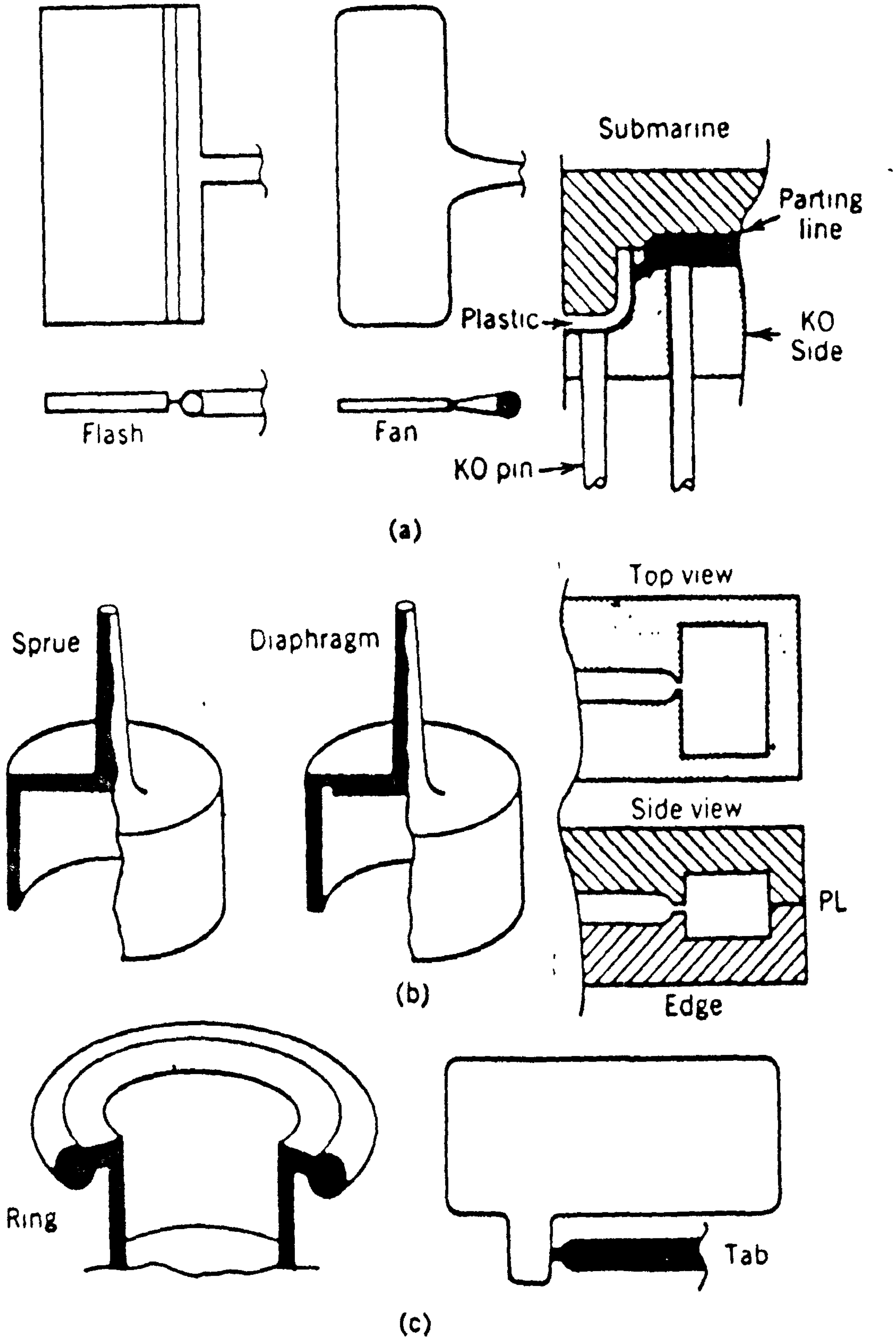
The gate should be large enough for suitable fill rate and small enough to seal off and prevent backflow or packing. If possible, gates should be located for economical removal and finishing of the molded part. Circular gates are recommended where applicable and they should be so located that the plastic melt leaving the gate impinges against a mold surface to build up a smooth flow of material into cavity thus preventing jetting and worming. Fig. 2.3 displays some of the gates types.

Selecting the proper gate, both in shape and size, is important in light of the aforementioned factors. The type of gates used are

1. *Rectangular gate* - Simplest form of gates a general purpose method.

2. *Fan gate* - It is very effective for uniform planning of large areas and thin sections. A general taper should be provided from runner to gate.

3. *Flash or slit gate* - Is particularly good for thin walled parts and low viscosity materials. It provides for rapid fill and quick gate seal-off.



2.3 TYPES OF GATES

4. *Tab gate* - It is combination of simple rectangular gating and a tab system. This style lends itself nicely to multi-cavity balanced runner layouts.

5. *Sprue gate* - Used to gate directly into the part when inserts or part design prevent using some other method; good for noncritical appearance parts.

6. *Tunnel or submarine gate* - It provides a self degating operation, internal within the mold, upon opening. This eliminates the need for operator to degate the part and thus the tunnel gate is easily adapted to automatic molding cycles.

Regardless of the gate used the gate land should be as short as possible to eliminate freeze-off of the material before filling. Gate lands as small as 0.020in. and as long a .09in. can be used successfully. A radius on the leading edge of the gate land will help in smoother material flow.

If possible, gates should not be positioned so that they feed a thin cross section of the part. Again, the idea is to keep the molten plastic moving and filling the cavity. The chances of doing this are much better when going from thick to thin than from thin to thick. The quantity and layout of gates should be flexible. Consideration must be given to adding more gates if required, or for completely changing the gate geometry if necessary.

A narrow gate is desirable. In multiple-cavity molds gates are used to balance flow. If the gates are small resin heats up the metal surrounding it where as if they are large it takes too long to freeze and there is not enough back pressure. Gates should be located when possible in a hidden area of the product. Location of the gate will determine the position of the vents. It is desirable, then to position the gate so that simple and adequate venting may be achieved.

2.6.1 Gate Design

Gate size, shape and location are responsible for material orientation, the pattern of flow, time and pressure to fill the cavity and temperature of the material as it enters the cavity.

Factors effecting the size of gate.:

1. The flow characteristics of the material to be molded.
2. The wall section of the molding
3. Volume of material to be injected into the mold.
4. Temperature of melt.
5. Temperature of mold.

Balanced gating :

To balance the flow into cavities there are two ways of varying the intersection.

1. Varying the land length.
2. By varying the cross sectional area of the gates.

2.7 Runners

The runners are the main channels feeding gates and should be given the same consideration and attention as the gates. The basic runner types are full round, half round, extended half round and trapezoidal. Some basic runner cross-sections are shown in fig. 2.4.

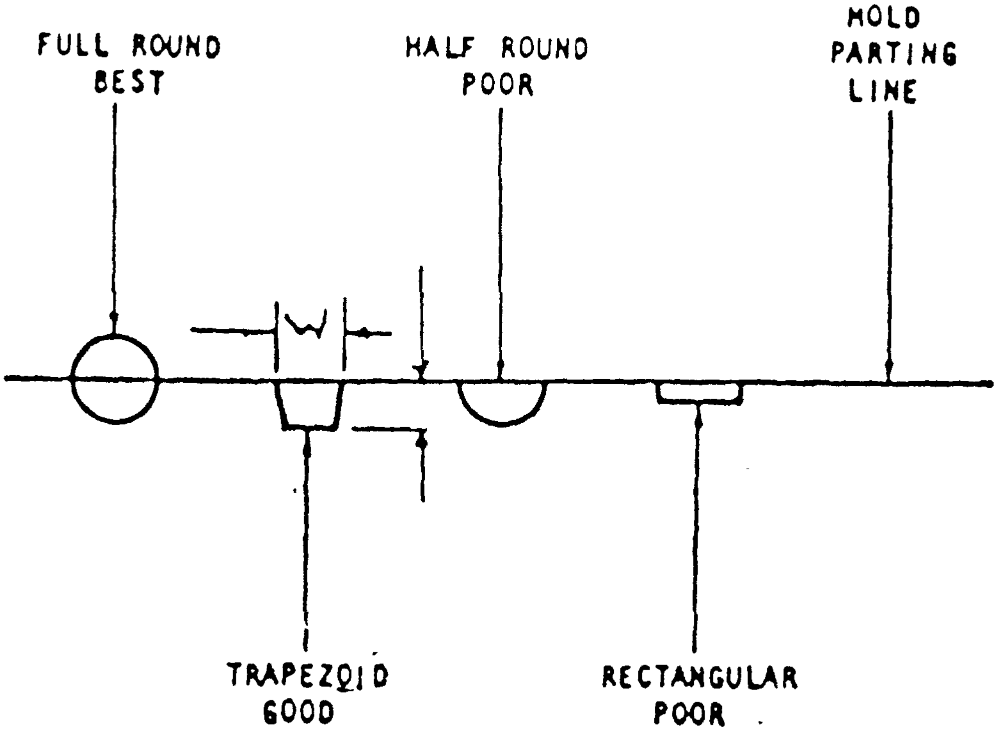


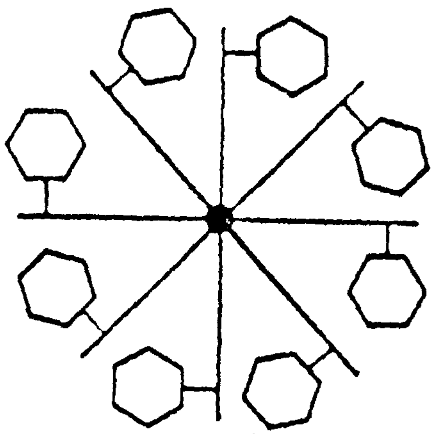
Fig. 2.4 Typical runner cross-sections

The full round runner is the preferred style, with trapezoidal and half round following the order. Full round offers the largest cross sectional area and the smoothest material flow pattern. Full round also provides the most uniform exposure to the mold surface. However, both halves of the mold must be machined.

The motion or movement of the molten plastic material through the runner can be classified as either a laminar or turbulent flow. Laminar flow or streamlined flow of thermoplastic material in a mold or runner system is achieved by solidification of the molten plastic layer in contact with the metal surface, thus providing an insulating tube through which more material flows. This type of flow is desirable for molded parts that require a minimum of stresses, and weld marks.

Runners should be kept as small as possible in order to reduce the cooling time, regrind volume and the projected area of the mold. The pressure drop on the flow of a plastic material gets less and less as the cross section gets smaller. Cold slug wells should be provided at the end of runners and at 90^{o} turns. If it is at all possible the cavities in injection molding should be equally distant from the sprue. They will allow the same length of runner flow.

The runner layout and consequently the cavity layout for multi cavity molds should always be balanced. This means that the distance from the sprue to every cavity should be equal. To provide cavity to cavity uniformity the runner system should enable all cavities to fill at the same rate and the same time. In multi cavity unbalanced or family molds the use of variable gate dimensions may be necessary to ensure that the cavities fill at the same rate. Balanced runner systems give the greatest uniformity of flow from the sprue to the different cavities which simplifies



Radial

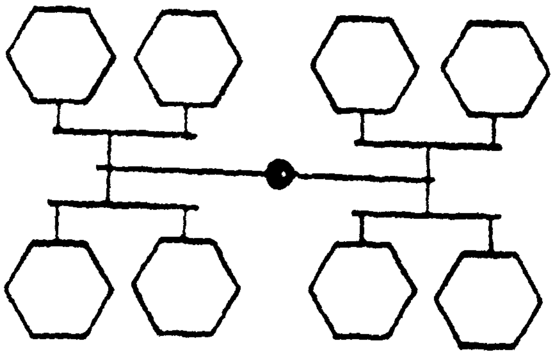


Fig. 2.5 Balanced runner designs

the maintenance of tight dimensional tolerances in multicavity molds. Some balanced runner designs are shown in fig 2.5.

When a runner layout is being developed for a part with overall dimensions, consideration should be given to large radius runners than sharp turns in order to better distribute the melt and cut down on secondary flows caused by sharp turns.

Provision should also made in the runner system to catch cold slugs. Cold slug wells as they are called should be designed into the layout. The idea here is to trap the cold slugs of plastic, which occur at the flow front. Runners branching off from the main runner should be reduced in size by 0.06in. in diameter.

Runner System :

1. It should transmit hot melt with minimum material and pressure drop waste from nozzle to gate.
2. The length of runner conduit must be kept at minimum level.
3. Cross section should be optimally set for low pressure drop, low material waste and relatively slow cooling avoiding premature solidification and short shots.

2.7.1 Runner and Gate Design

Molds should be designed for economic operations.

1. Use of reduced transfer and injection pressure.
2. Minimum waste material in all runners and gates.
3. Maximum heat build up to obtain short cure cycles.
4. Ease of removing gates from the article.

Runners should be circular in cross section since they offer minimum resistance to flow, and the most effective insulation of the center of the stock against the heat of the mold block which tends to advance the material. Circular cross section is used to minimize heat loss. Runners should be short as possible to prevent waste and precure. Design to avoid sudden changes in direction and with generous radii when changing the direction of flow. In a basic two plate mold the runner is positioned on the parting surface.

In designing a runner we have to consider :

1. The shape of the cross section of the runner.
2. The size of the runner.
3. Runner layout

As plastic melt progresses through a runner the melt on the cold mold surface solidifies as its temperature decreases and it acts as a insulation to the melt in the middle. Therefore the gate should be positioned in line with the center of the runner. Length of the runner should be kept short for better material flow and speed of transfer in filling the cavities.

Deciding factors for the size of runner

1. Wall section and volume of the mold.
2. Distance of cavity from the main runner or sprue.
3. Runner cooling considerations.
4. Range of mold makers cutters available.
5. Plastic materials to be used.

As the length of the runner increases the diameter of the runner also increases. Diameter of the runner should not be more than 10mm or less than 2 mm. But for polymers with high viscosity diameter can be increased upto 0.5 inch (i.e PVC, Acrylics)

2.7.2 Hot Runners

The resin melt flows from the cylinder nozzle into heated channels to the mold then through sub-nozzles into the regular sprue of the mold cavity.

2.8 Gate and Runners for Injection Molded thermosets

The runner and gate system for injection molded thermosets should be designed to avoid excessive frictional heat build up in the plastic material. The runner system should be full round and sharp corners at runner bends should be avoided. Most molds have replaceable gates and runner sections. They can be easily replaced if they wear in production. The molds should be chrome plated to reduce wear and eliminating sticking.

2.9 Cavities

The nucleus of any mold is the cavity itself. The plastics part produced in the cavity will be a direct reproduction of its surfaces. With this in mind factors such as sectioning maintenance, tool cost, and production quantities should be considered.

Sectional cavities are preferred where part design allows. It means if a plastic part has many external radii and nmatch lines on the part surface should be objectionable, successful sectioning of the mold cavity is highly unlikely. Sectional cavities are those that made from several pieces rather than one unit.

It offers many advantages. reaction to change can be handled more easily and faster, with less overall cost and delivery time. Use of more versatile machining methods and easier overall mold maintenance are certainly important plusses. Adjustments and closer dimensional control can be had with sectioned cavities. Alignment between cavity and force is made easier by using sectional construction.

Molds used to produce plastics parts are usually very expensive and time consuming to build, in many cases, the part can be manufactured in no other way. Under circumstances such as these the mold must be accurate, clearly defined and practical.

CHAPTER III

SIMULATION OF INJECTION MOLD FILLING WITH MOLDFLOW

3.1 Introduction

MOLDFLOW programs analyze the flow of plastics into injection molds by solving simultaneously the continuity, momentum and energy equations for flow. These programs are used in two areas. One set of programs is used for mold design and is commercially important. It is used for positioning gates, dimensioning runner systems, designing flow leaders and deflectors to improve flow within the cavity.

In this context the company has developed three programs that solve the situations encountered in plastics injection molding. These programs perform finite element analyses which generate information for the design of injection molds and injection molded parts. The second set of MOLDFLOW programs is used in scientific and laboratory applications. There are two programs for this purpose, a materials database and a material selection package. The input data to these programs include specific heat, thermal conductivity and density, and viscosity as a function of temperature, pressure and shear rate [9].

3.2 MOLDFLOW BASIS

Pressure drop over any section of a molding is affected by the viscosity of the plastic melt, and this is affected by heat transfer. In turn the pressure drop and resultant shear stresses will effect frictional heating. Therefore, both viscosity and the temperature are inter related [9].

Mold flow programs consider the viscosity of the plastic as a function of shear rate and temperature, and also consider heat transfer and induced frictional heat. They solve the simultaneous equations of heat transfer and fluid flow.

There are three basic generation of moldflow programs available.

3.2.1 SINGLE FLOWS

In this flow path is broken up into number of sections. It is assumed that the plastic entering one section is identical to the plastic leaving the previous section, so giving a very simple flow pattern.

3.2.2 BRANCHING FLOWS :

Program MF uses the branching flow approach. The flow is considered to start from one section, flow some distant, and then split into a number of flows, which, in turn, may split again [10]. There is an intrinsic assumption that flow from upstream is equal to the flow out.

Flow paths are broken up into a number of sections, and there are three basic types of sections- round, rectangular and radial.

The average conditions in sections in terms of temperature, shear rate, shear stress, viscosity, etc are assumed to be constant. In particular this means that frictional heating is not added on until the end of each section. In using branching flow technique it is assumed that the element is aligned in the direction of flow.

3.2.3 FINITE ELEMENTS

In this molding is considered to be made up of number triangular elements and the flow conditions, i.e. direction of flow, shear rate, shear stress, viscosity, etc, are considered to be constant over each element.

In the finite element technique, the iterating approach is used. The computer does not know the filling pattern. In all cases the mathematical model used is one of controlled flow rate, i.e. the flow rate is specified directly or indirectly.

3.3 BRIEF DESCRIPTION OF THE PROGRAMS

WFILG	A moldfile writer for 2-D Moldflow program MF
MFREAD	A diagnostic program for checking moldfiles, with editing facility.
MATDB	A materials database with editing, search and inspect facilities.
VISDAT	Processes the experimental viscosity data from a high shear viscometer to a form suitable for the moldflow materials database.
MF	A menu driven flow analysis program, using the branching flow technique, that will predict pressures, fill times, temperatures, shear stresses, and shear rates.
SMOD	2-D wire frame/surface modelling program.
FMESH	An automatic mesh-generator for meshing any irregular surfaces.

MFL2	A finite element 3D flow analysis program using a waveband growth scheme. Only one injection point is available but any number of gates connected with hot or cold runners is allowed.
FRES	The display program which plots isobars, isotherms, and isochrones onto a Finite element model to give an indication of flow pattern.
MP	Precision 2D Flow Analysis.
DRES	Enhanced version of FRES
MFL3	A finite element 3D flow analysis program using a nodal growth scheme. Only one injection point is available but any number of gates connected with hot or cold runners is allowed. The program also features profiled injection and intermediate results files.

3.4 FLOW TECHNOLOGY

The MOLDFLOW programs consider the dependence of viscosity of plastics on temperature and shear rate to calculate viscosity at a point and predict pressure distribution. Viscosity, temperature and shear will vary depending on the flow rate. Also, flow rate varies with viscosity. Thus flow and viscosity are interlinked. The programs analyze single sections to predict pressure and temperature over the sections and this analysis is extended to develop a total mechanism to predict pressure, temperature and flow patterns in a complex molding.

These programs solve the mathematical equations of heat transfer and fluid flow using a finite difference scheme. Flow paths are defined by simple strip geometries which are broken into sections . These sections are divided into a number of slices having their own temperature, shear rate and viscosity. The normal heat transfer equations are used to calculate the heat transfer into each slice and the flow is analyzed by solving the flow equations by numerical integration over the section.

A significant amount of computer power is required to run these programs. Near the frozen layer, conditions of high shear and low temperature prevail, and the experimental results are most prone to error, rendering the results very dependent on the analysis in this region. These schemes work well in most applications but the development of simpler algorithms based on dimensionless analysis and curve fitting schemes results in more practical systems.

For an isothermal flow, first the shear rate is calculated and then the viscosity based on shear rate and temperature. This viscosity is used in standard mold filling calculations. In a practical situation hot plastic flows into a cold mold leading to a frozen skin formation. Hence, the thickness of the frozen layer should be calculated and then the effects of temperature distribution across the channel should be determined. This problem is solved by introducing dimensionless analysis.

In order to achieve the goal of the process simulation effectively, it is assumed that the filling stage is responsible for the most significant and substantial physical changes of the polymer melt, although some important properties of the part such as residual stress are determined during post filling stages [11].

Injection molded parts have thin, three dimensional shapes, which can be unfolded tp appropriate two dimensional layflats, for the purpose of analysis. Due to relatively low thermal conductivity of the polymer melts, the thickness of the part should as thin as allowable for the intended functional requirement. Furthermore the thickness should as uniform as possible to avoid sink marks, distortion, cooling stresses and jetting phenomena. Therefore it is possible to use a two dimensional flow model in the filling simulation for quite complicated geometry of molds by making an approximated two dimensional mold cavity.

3.5 MODEL DESCRIPTION

In the simulation process 2-D layflat model having two cavities with same volume are created using WFILG program. They are created as sections. We analyze the sections which we assume as runners, gates and cavities specifying the molding conditions, i.e mold temperature, melt temperature and time to fill for each material. Program MATDB provides the material data. The program MF is used for this purpose which takes the file created in WFILG as its input. MF has different options like, to analyze single section or all the sections, to balance the sections, to scan the injection time and to change the mold dimensions.

WFILG

The purpose of this program is to assist the user creating the mold files required by the 2-D Moldflow program MF. The input is in the form of X, Y and Z coordinates of nodes, each node is an end point of a flow section conventional to all 2D software. When creating a flow model, start with the longest flow first. The flow sections are drawn relative to the X-Z plane. The flow model is displayed on the graphics screen. The alpha screen overlays the graphics screen and all the user input is echoed on the alpha screen.

MATDB

This program provides all the editing, searching and data inspection facilities required for Moldflow work. The database consists of two distinct regions, standard and personal. The standard region contains material data, generated by material suppliers and maintained by Moldflow. Standard database cannot be edited. Personal database can be modified in any way the user sees fit . This program supplies plastic supplier's name, grade and material data i.e properties, variables and points.

MF

It is the main flow analysis and balancing program of the branching flow, non-graphic, suite of programs. The analysis of hot runners are also completed using the MF program. The MF program will analyse flow in cavities and runners systems, dimension runners, balance flow in cavity and offer alternative variations of optimum molding conditions [12]. The program is menu driven and the output is tabular. The description of the product and runner system to the computer is created by program WFILG.

Using the MF program the runners are balanced using the flow balance option. MF analyses the sections after they are balanced and gives the pressure, pressure drop, pressure gradient, stress, shear rate, temperature, cooling time at each section. Our objective of studying the influence of natural wear and tear in gates and runners on the mold filling and molded part is achieved by varying the cross sectional area of the gates and runners.

Different models are used for this purpose.

1. Rectangular runner with circular gate.
2. Rectangular runner with rectangular gate.
3. Rectangular runner with circular gate.
4. Circular runner with circular gate.

One of the two cavities is unbalanced by varying the dimensions of rectangular gate,(length, width, depth) individually and then combined keeping runner dimensions constant. The data is collected for this wear. Then by changing the molding conditions we try to balance the cavity again. The change in time of fill and flow rate are noted for each variation. The data is collected using six different materials. While the gate dimensions are changed the runner dimensions are kept constant and and the vice versa. In case of circular gates diameter and length are varied. The above procedure is repeated for different configurations mentioned above. The table of materials and the respective molding conditions are given in table 3.1 & 3.2.

3.6 FLOW BALANCING

The main objective of carrying out a MOLDFLOW analysis is to achieve balanced flow in the following areas [13].

1. Within a cavity with one gate or within each sub-molding of a cavity fed by a gate.
2. Between each gate of a multicavity family mold so that each cavity is delivered of the correct flow rate of melt at the optimum conditions of temperature, pressure and time.

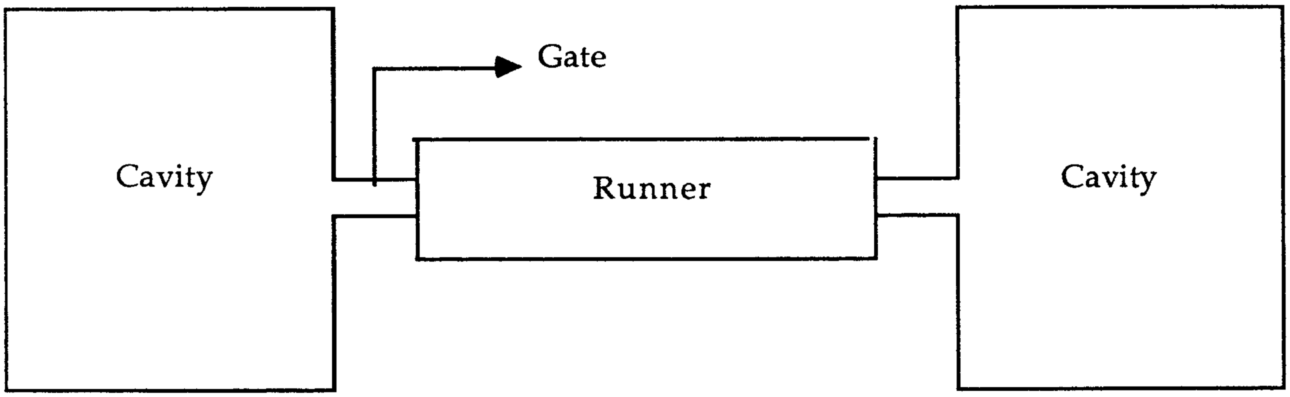


Fig. 3.1 Circular Gate with Rectangular Runner
Dimmensions in mm--
Runner: 101.6 x 3.24 x 4.76
Gate: 0.76 x 1.52 dia
Cavity: 101.6 x 2.54 x 5.6

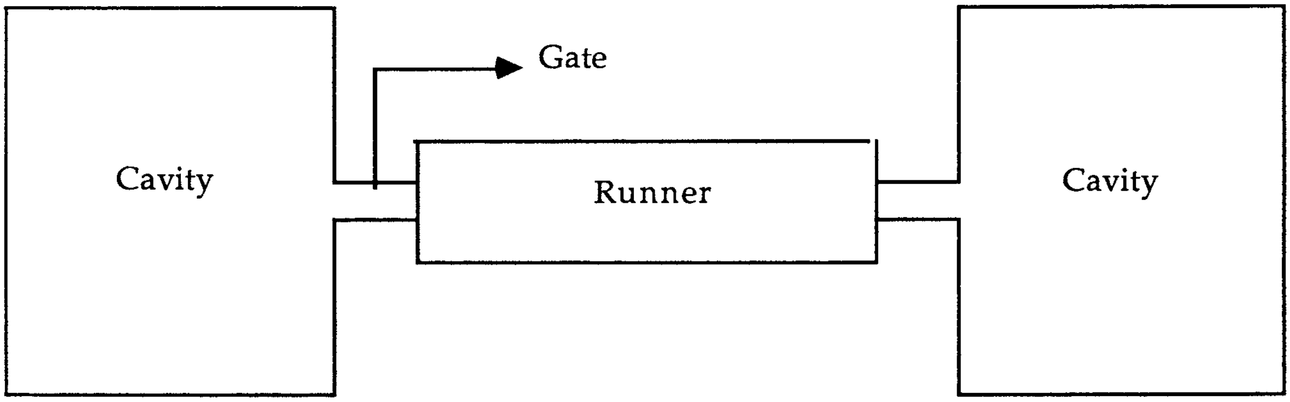


Fig. 3.2 Rectangular Gate with Rectangular Runner
Dimmensions in mm --
Runner: 101.6 x 3.24 x 4.76
Gate: 0.76 x 0.76 x1.52
Cavity: 101.6 x 2.54 x 5.6

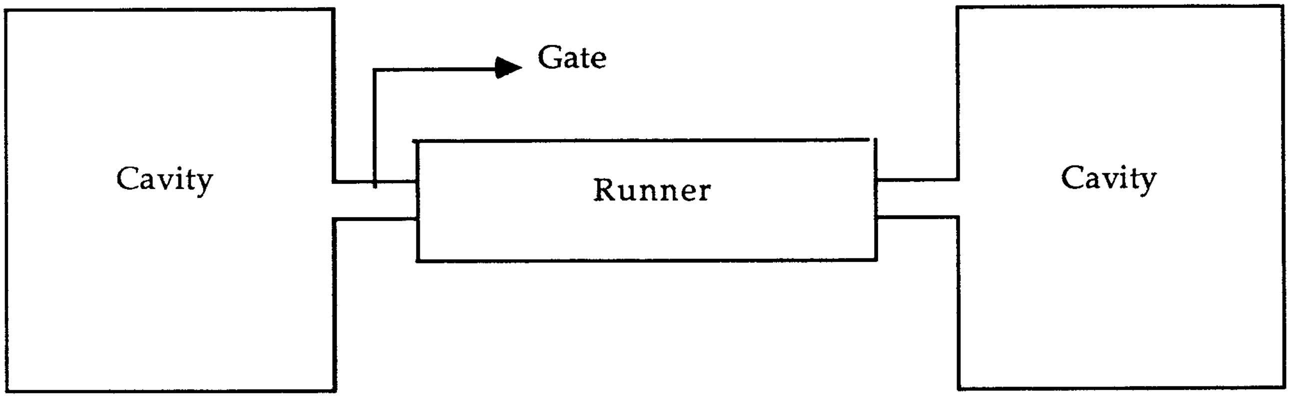


Fig. 3.3 Circular Gate with Circular Runner
Dimmensions in mm--
Runner: 101.6 x 4.76 dia
Gate: 0.76 x 1.52 dia
Cavity: 101.6 x 2.54 x 5.6

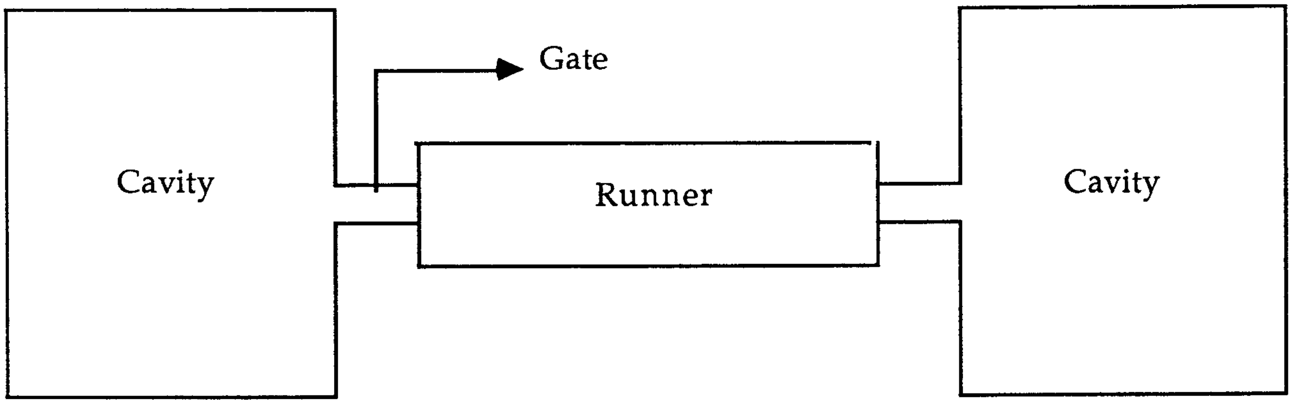


Fig. 3.4 Circular Gate with Rectangular Runner
Dimmensions in mm --
Runner: 101.6 x 3.24 x 4.76
Gate: 0.76 x1.52 dia
Cavity: 101.6 x 2.54 x 5.6

Table of Materials

	Material	Manufacturer	Trademark	Grade
1	PC	**Enichem**	SINVET221	E101
2	PP	HIMONT	PROFAX 72	HM 100
3	PA6	EMS	GRILONA	EM100
4	PBT	POLYPLASTICS	DURANEX 2000	PO2104

Table 3.1

Table of Molding Conditions

	Material	Tmold °C	Tmelt °C	Time of fill (sec)
1	PC	60	300	3
2	PP	20	260	2
3	PA6	80	260	2
4	PBT	60	260	2

Table 3.2

3. Between all the runners of a multiple runner system so that melt is delivered at each individual gate at the conditions required to fill the balanced cavities,and at the same time use the minimum amount of material in the most economical fill time.

Unbalanced flow within a cavity will cause over packing which is the main cause of stress concentration, warping, sink marks, etc. Unbalanced flow in a runner system will starve some cavities or sub-moldings, while overpacking others, with all the attendant problems, and with inconsistent quality being produced using a usually very narrow band of machine settings. When a runner system is used to flow balance the total fill pressure (runner + cavity pressure drop) must be equal in each flow system. It is insufficient to balance the runners only, with out considering the cavity. Changing the runner system will alter the cavity pressure drop because the flow rate will alter.

CONSTANT PRESSURE GRADIENT :

Runners are designed using the constant pressure gradient principle to give lowest possible volume for given pressure drop. Pressure gradient is the pressure drop per unit length. An ideal fill should have constant pressure gradient.

MAXIMUM SHEAR STRESS :

This is shearing force by area . As it is force related it is dependant on the viscosity of the material under differing molding conditions. Maximum value value allowable is of the order of 1% of tensile strength of material.

UNIFORM COOLING TIME :

Cooling time throughout the part should be uniform to obviate warping due to different cooling rates. Variations in cooling are caused by friction induced local cavity heating and by poor mold cooling design. The effects of this are most pronounced when using crystalline materials.

3.7 Integration of Technologies

MOLDFLOW has developed three processing programs which integrate the functions of processing and displaying geometric data.

3.7.1 SMOD

SMOD is a wire frame model generator which is used to create the geometric model for use in the finite element analysis programs. The part geometry can be defined and the part can be displayed on a computer screen. The model is ready to be meshed by the FMESH program. SMOD is driven by a command language and the information is stored in three files having the general model information, point coordinate information and surface information.

3.7.2 FMESH

FMESH is an automatic mesh generator suitable for all kinds of surfaces. It can read SMOD files and ASCII files created from the keyboard. FMESH is driven by a command language. The mesh density can be controlled by defining the number of divisions across the model. The mesh can be generated across a curve so that it can create a 3-D faceted surface without defining a multitude of surfaces.

3.7.3 FRES

FRES displays the simulation of flow, temperature distribution, cooling and stress patterns. Thus it displays isobars, isotherms and isochrones. Isobars are lines that join points at equal pressure, isotherms join points at equal temperature and isochrones simulate short shots by joining points that are filled at the same time interval.

3.8 MOLDFLOW Analysis Features

MOLDFLOW is a CAD software that attempts to model the injection molding process by using finite element methods and simulating techniques, to provide an interactive graphics package. The program effectively simulates the cavity filling process that predicts part dimensions and properties before manufacturing the part [15]. Thus the part designer knows the outcome of the design and any changes that may be required can be made in the design stage.

The prototyping time and cost is almost eliminated, thus reducing part cost and cycle time. The disadvantage that some molders find is that initial cost of the software is much [11]. This software does not consider shrinkage into account when designing molds. It can be interfaced with solid modeling design software and CAD/CAM systems [16].

3.9 MOLDFLOW Thermoplastic and Thermosets Flow Analysis features

Flow Analysis : The programs consider the heat transfer and flow dependence on shear and temperature to calculate viscosity and predict pressure distribution. In mathematical terminology, simultaneous equations of heat transfer and fluid flow are solved.

Project Planning : This helps in approaching individual MOLDFLOW projects.

Modelling : This part of the software helps to select the right modelling approach.

Materials Selection : The package maintains a database of materials which is used for mold design and research.

CAD/CAM Interface : This part helps in interfacing Computer Aided Drafting Systems with MOLDFLOW.

CHAPTER IV

4. RESULTS

Four materials Polycarbonate, Polypropylene, Nylon 6 and Polybutylene Terephthalate were used for studying the influence of wear and tear in gates and runners in a balanced multi-cavity mold on performance. The data is collected for the cavity layouts shown in figures 3.1, 3.2, 3.3 and 3.4. The results are presented graphically in this chapter. Our concern was to see how the flow rate and time of fill were changing when one of the cavities was imbalanced. Then by changing the molding conditions it was attempted to balance the cavities again and note the respective fill times and flow rates.

4.1 Results for wear in Circular gates

The concern with circular gates was wear in the radial and axial directions.

4.1.1 Influence of radial wear on time of fill

Figures 4.1, 4.5, 4.9 and 4.13 represent the changes in fill time for radial wear. The wear varies from 1.52 mm to 1.68 mm. Operating conditions are also displayed in the figures for different materials. In all the four cases the gate diameter has increased and the time of fill decreased linearly. They varied for each material and they are as follows.

Polycarbonate	3	-	2.63
Polypropylene	2	-	1.87

Nylon 6	2	-	1.78
PBT	2	-	1.76

4.1.2 Influence of radial wear on flow rate

Figures 4.2, 4.6, 4.10 and 4.14 represent the flow rates for varying radial wear. Amount of wear is same as before. Flow rate increased almost linearly for all the materials as the radial wear increased. Flow rate varied as follows

Polcarbonate	9.95	-	11.4
Polypropylene	14.92	-	16
Nylon 6	14.92	-	16.8
PBT	14.92	-	17

4.1.3 Percentage change in time of fill and flow rate for radial wear

The amount of deviation or the percentage change in flow rates and time of fill are calculated and can be seen in the figures 4.65, 4.66, 4.67 and 4.68. Graphs display the percentage change along the Y-axis. As explained previously as the gate wear increased time of fill and flow rate changed quite noticeably. The deviation is particularly more in case of flow rate. The percentage of variation for different materials is as follows

For time of fill

Polycarbonate	0	-	12.4 %
Polypropylene	0	-	6.5 %
Nylon 6	0	-	11 %
PBT	0	-	12 %

For flow rate they are as follows :

Polycarbonate	0	-	14 %
Polypropylene	0	-	6.7 %
Nylon 6	0	-	12.3 %
PBT	0	-	13.6 %

4.1.4 Influence of axial wear on time of fill

The gate length is decreased in this, and it varies from .76 mm to .61 mm. Figures 4.3, 4.7, 4.11 and 4.15 represents influence of axial wear on time of fill. As the gate length varied the time of fill also decreased. The values of time of fill varied as shown below :

Polycarbonate	3	-	2.74
Polypropylene	2	-	1.89
Nylon 6	2	-	1.85
PBT	2	-	1.85

4.1.5 Influence of axial wear on flow rate

Similarly Figures 4.4, 4.8, 4.12 and 4.16 gives the flow rate for varying axial wears. We can observe from the figures the flow rate increased as length decreased. Flow rate varied as follows :

Polycarbonate	9.95	-	10.9
Polypropylene	14.92	-	15.8

Nylon 6	14.92	-	16.1
PBT	14.92	-	16.1

4.1.6 Percentage change in time of fill and flow rate for axial flow

Figures 4.69, 4.70, 4.71 and 4.72 represent the percentage change in flow rate and time of fill for axial wear of a circular gate. As the gate length wore from .76 mm to .61 mm the flow rates and time of fill changed significantly. Variation s are different for four different materials and they are as follows :

For time of fill

Polycarbonate	0		8.7 %
polypropylene	0	-	5.5 %
Nylon 6	0	-	7.5 %
PBT	0	-	7.5 %

For flow rate

Polycarbonate	0	-	9.4 %
Polypropylene	0	-	5.8 %
Nylon 6	0	-	8.1 %
PBT	0	-	8.1 %

4.2 Results for wear in Rectangular gates

Rectangular gate of dimensions .76 * .76 * 1.52 mm is used for the purpose. Gate length varied from .76 mm to .61 mm. Width of the gate varied from 1.52 mm to 1.68 mm. Depth of the gate is varied from .76 mm to .91 mm.

4.2.1 Influence of wear in width on time of fill

Figures 4.17, 4.23, 4.29 and 4.35 represent the results for materials PC, PP, PA6 and PBT respectively. Time of fill decreased as the wear in width increased. The decrease was not linear for PP, PA6 and PBT. The variation is as follows:

Polycarbonate	3	-	2.82
Polypropylene	2	-	1.95
Nylon 6	2	-	1.9
PBT	2	-	1.88

4.2.2 Influence of wear in width on flow rate

From the figures 4.18, 4.24, 4.30 and 4.36 we see the influence of wear in width on flow rate. Flow rate increased for all the materials as the wear in the width increased. The variation was linear for PC but was not the same for remaining materials PP, PA6 and PBT. The values for variations are

Polycarbonate	9.95	-	10.6
Polypropylene	14.92	-	15.3
Nylon 6	14.92	-	15.7
PBT	14.92	-	15.9

4.2.3 Percentage change in time of fill and flow rate for wear in width

The results for time of fill and flow rate are plotted on the same graph against wear in width in figures 4.73, 4.74, 4.75 and 4.76. The percentage change from original values was more for flow rate than time of fill. The difference was not much for small wear but as the wear increased we can clearly observe the increase of one wear over another. Deviations are as follows:

For time of fill

Polycarbonate	0	-	6 %
Polypropylene	0	-	2.5 %
Nylon 6	0	-	5 %
PBT	0	-	6 %

For flow rate

Polycarbonate	0	-	6.3 %
Polypropylene	0	-	2.5 %
Nylon 6	0	-	5.2 %
PBT	0	-	6.4 %

4.2.4 Influence of wear in depth on time of fill

As shown in figures 4.19, 4.25, 4.31 and 4.37 time of fill decreased as the wear in depth increased. The decrease was proportional to the amount of wear. Variations for different materials are as follows:

Polcarbonate	3	-	2.09
Polypropylene	2	-	1.65
Nylon 6	2	-	1.42
PBT	2	-	1.37

4.2.5 Influence of wear in depth on flow rate

Figures 4.20, 4.26, 4.30 and 4.38 display the results for this. Flow rate increased as the wear in depth increased. The increase is almost proportional to the increase in wear. The exact increase is as follows:

Polycarbonate	9.95	-	14.3
Polypropylene	14.92	-	18.1
Nylon 6	14.92	-	21
PBT	14.92	-	21.8

4.2.6 Percentage change in time of fill and flow rate for wear in depth

As the case in wear in width the percentage change is quite significant. The deviation is more in case of flow rate than in time of fill. This can be observed from figures 4.77, 4.78, 4.79 and 4.80. The values varied as follows

For time of fill

Polcarbonate	0	-	30.4 %
Polypropylene	0	-	17.5 %
Nylon 6	0	-	29 %
PBT	0	-	31.5 %

For flow rate

Polycarbonate	0	-	43.5 %
Polypropylene	0	-	21.2 %
Nylon 6	0	-	40.8 %
PBT	0	-	46 %

4.2.7 Influence of wear in length on time of fill

Figures 4.21, 4.27, 4.33 and 4.39 represent the results for materials PC, PP, PA6 and PBT respectively. Time of fill decreased as the wear decreased. The decrease was almost linear for PC, PP, PA6 and PBT. The variation is as follows:

Polycarbonate	3	-	2.51
Polypropylene	2	-	1.8
Nylon 6	2	-	1.71
PBT	2	-	1.7

4.2.8 Influence of wear in length on flow rate

From the figures 4.22, 4.28, 4.34 and 4.40 we see the influence of wear in length on flow rate. Flow rate increased for all the materials as the wear in the length decreased. The variation was linear for PBT but was not the same for remaining materials PC, PP and PA6. The values for variations are

Polycarbonate	9.95	-	11.9
Polypropylene	14.92	-	16.6
Nylon 6	14.92	-	17.5
PBT	14.92	-	17.5

4.2.9 Percentage change in time of fill and flow rate for wear in length

The results for time of fill and flow rate are plotted on the same graph against wear in length in figures 4.81, 4.82, 4.83 and 4.84. The percentage change from original values was more for flow rate than time of fill. The difference was not much for small wear but as the wear increased we can clearly observe the increase of one wear over another. Deviations are as follows:

For time of fill

Polycarbonate	0	-	16.4 %
Polypropylene	0	-	10 %
Nylon 6	0	-	14.5 %
PBT	0	-	15 %

For flow rate

Polycarbonate	0	-	19.5 %
Polypropylene	0	-	11.1 %
Nylon 6	0	-	16.9 %
PBT	0	-	17.6 %

4.3 Results for wear in Circular runners

4.3.1 Influence of radial wear on time of fill

Figures 4.41, 4.43, 4.45 and 4.47 represent the changes in fill time for radial wear. The wear varies from 4.76 mm to 4.94 mm. Operating conditions are also displayed in the figures for different materials. In all the four cases the gate diameter increased the time of fill decreased linearly. They varied for each material and they are as follows.

Polycarbonate	3	2.56
Polypropylene	2	1.74
Nylon 6	2	1.79
PBT	2	1.82

4.3.2 Influence of radial wear on flow rate

Figures 4.42, 4.44, 4.46 and 4.48 represent the flow rates for varying radial wear. Amount of wear is same as before. Flow rate increased almost linearly for all the materials as the wear increased. Flow rate varied as follows

Polcarbonate	10	-	11.7
Polypropylene	14.92	-	17.2
Nylon 6	14.92	-	16.8
PBT	14.92	-	16.5

4.3.3 Percentage change in time of fill and flow rate for radial wear

The amount of deviation or the percentage change in flow rates and time of fill are calculated and can be seen in the figures 4.85, 4.86, 4.87 and 4.88. Graphs display the percentage change along the Y-axis. As explained previously as the gate wear increased time of fill and flow rate changed quite noticeably. The deviation is particularly more in case of flow rate. The percentage of variation for different materials is as follows for time of fill

Polycarbonate	0	-	14.7 %
Polypropylene	0	-	13 %

Nylon 6	0	-	10.5 %
PBT	0	-	9 %

For flow rate they are as follows :

Polcarbonate	0	-	17.6 %
Polypropylene	0	-	15.5 %
Nylon 6	0	-	12.3 %
PBT	0	-	10.4 %

4.4 Results for wear in Rectangular runners

4.4.1 Influence of wear in width on time of fill

Figures 4.49, 4.53, 4.57 and 4.61 represent the results for materials PC, PP, PA6 and PBT respectively. Time of fill decreased as the wear increased. The decrease was not linear for PC, PP, PA6 and PBT. The variation is as follows:

Polycarbonate	3	-	2.92
Polypropylene	2	-	1.96
Nylon 6	2	-	1.96
PBT	2	-	1.96

4.4.2 Influence of wear in width on flow rate

From the figures 4.50, 4.54, 4.58 and 4.62 the influence of wear in width on flow rate can be observed.

Flow rate increased for all the materials as the wear in the width increased. The variation was not linear for all the materials. The values for variations are

Polycarbonate	9.8	-	10.1
Polypropylene	14.7	-	15.0
Nylon 6	14.7	-	15.0
PBT	14.7	-	14.98

4.4.3 Percentage change in time of fill and flow rate for wear in length

The results for time of fill and flow rate are plotted on the same graph against wear in width in figures 4.89,4.90, 4.91 and 4.92. The percentage change from original values was more for flow rate than time of fill. The difference was not much for small wear but as the wear increased we can clearly observe the increase of one wear over another. Deviations are as follows:

For time of fill

Polycarbonate	0	-	2.7 %
Polypropylene	0	-	2.0 %
Nylon 6	0	-	2 %
PBT	0	-	1.5 %

For flow rate

Polycarbonate	0	-	2.9 %
Polypropylene	0	-	2.2 %
Nylon 6	0	-	2.2 %
PBT	0	-	1.7 %

4.4.4 Influence of wear in depth on time of fill

As shown in figures 4.51, 4.55, 4.59 and 4.63 time of fill decreased as the wear in depth increased. The decrease was proportional to the amount of wear. Wear in depth was from 3.24 mm to 3.43 mm. Variations for different materials are as follows:

Polcarbonate	3	-	2.45
Polypropylene	2	-	1.68
Nylon 6	2	-	1.74
PBT	2	-	1.77

4.4.5 Influence of wear in depth on flow rate

Figures 4.52, 4.56, 4.60 and 4.64 display the results for this. Flow rate increased as the wear in depth increased. The increase is almost proportional to the increase in wear. The exact increase is as follows:

Polycarbonate	9.95	-	12.0
Polypropylene	14.92	-	17.5
Nylon 6	14.92	-	16.9
PBT	14.92	-	16.6

4.4.6 Percentage change in time of fill and flow rate for wear in depth

As the case in wear in width the % change is quite significant. The deviation is more in case of flow rate than in time of fill. This can be observed from figures 4.93, 4.94, 4.95 and 4.96. The values varied as follows

For time of fill

Polcarbonate	0	-	18.4 %
Polypropylene	0	-	16 %
Nylon 6	0	-	13 %
PBT	0	-	11.5 %

For flow rate

Polycarbonate	0	-	22.8 %
Polypropylene	0	-	19.4 %
Nylon 6	0	-	15.3 %
PBT	0	-	13.4 %

CHAPTER - V

DISCUSSION

In this chapter the massive amount of data collected from the program MF will be analyzed Since the purpose of the present study is to determine the influence of wear and tear in gates and runners in a balanced multicavity mold, the deviations of time of fill and flow rate from the ideal conditions (i.e when the gates and runners are undamaged) will be compared. As there is no previous study on this subject the discussion is completely based on the data collected.

The data collected for each configuration will be discussed separately and then compared. Results for gates and runners are also compared. Finally, each material is compared for the same mold.

5.1 Influence of Wear and Tear in Circular Gates.

As the radial wear increased there was gradual increase in flow rate and decrease in time of fill as is evident from the figures 4.65 to 4.72 for circular gate wear. It was assumed that there was only wear in gates, and that runner dimensions were constant.

Effects are, pressure at entrance of runner has decreased, stress increased and even the temperature slightly increased. As two cavities of equal volume were used when one of the gates was damaged, the pressure required did not change and even the flow rate was not affected. But when it was tried to balance the damaged gate, the pressure required to fill and flow rate increased considerably. This confirms they have significant influence.

5.1.1 Effect of radial wear on flow rate and time of fill

For radial wear the percentage change in time of fill was 12.4 for PC. For PP the decrease was only 6.5 percent compared with 11 and 12 percent for PA6 and PBT. Similarly deviations in flow rate are 14 percent for PC, 6.7 percent for PP, 12.3 and 13.6 percent in case of PA6 and PBT respectively. Results show the rheological properties influence the flow of material. Polypropylene is not as sensitive as the other three materials to dimension changes. The percentage change in flow rate is slightly higher than for time of fill.

5.1.2 Effect of axial wear on flow rate and time of fill

As with radial wear, there was deviation in flow rates and time of fill for axial wear and they were linearly distributed. PP seems to be less sensitive to the effects of wear and tear. The deviation was more in the case of PC. Percentage changes in both cases is the same for PA6 and PBT. Comparing the values for time of fill and flow rate the increase of one over other is 8 percent for PC, 5 percent for PP, 8 percent for PA6 and PBT.

5.1.3 Comparison of the effects of radial and axial wear

From the results for radial wear and axial wear, that effect of radial wear on time of fill and flow rate was more than for axial wear. In terms of actual percentage changes for time of fill they are 42 for PC, 18.2 for PP, 46.6 for PA6 and 60 for PBT.

Increases in terms of flow rate are 48.9% for PC, 15.5% for PP, 51.9% for PA6 and 67.9% for PBT. For circular gates PBT is the most sensitive and PP the least sensitive to dimensional changes.

5.2 Influence of Wear and Tear in Rectangular Gates

5.2.1 Effect of wear in width on flow rate and time of fill

The deviation can be observed from the figures 4.73 to 4.76. PC exhibits greater changes in time of fill and flow rate compared to other materials. Similar to circular gates, PP is less sensitive. The deviation from the original data of time of fill and flow rate is proportional for all the four materials.

5.2.2 Effect of wear in depth on flow rate and time of fill

The effect of wear in the depth is high for all the materials. In terms of time of fill the amount of decrease was highest for PBT (31.5%) followed by PC (30.4%), PA6 (29%) and PP (17.5%). For flow rate the increase is PC (43.5%), PP (21.2%), PA6 (40.8) and PBT (46%). It is evident from the above values flow rate is more when compared to time of fill. As seen with wear in width material PP is less sensitive for the wear and tear. PBT is highly sensitive for the changes. This influence can be observed in figures 4.77 to 4.80.

5.2.3 Effect of wear in length on flow time and time of fill

In this case, PC is more sensitive to the wear and tear and PP the least sensitive. The average change in value is between 10 to 20 percent. When one of the gates was damaged, there was no change in flow rate for other flow but when to balance of the damaged gate was attempted, there was an increase in flow rate.

5.2.4 Comparison of the effects of wear in width, wear in depth and wear in length

Effect of wear in depth has a greater increase when compared to wear in other directions. The deviation from the original datum is more than 15 % and reaching 46% in the case of PBT. For all situations PP is the least sensitive. PC is more sensitive. So thickness of the gate should be designed very carefully. The deviation is greater in the case of wear in the length than in wear in the depth. In all the wears there is no change in the flow rate at the other end. But the shear rate at the other undamaged gate increases significantly.

When wear in width and depth are compared for time of fill there is great difference for PC (6%, 30.4%), PP (2.5%, 17.5%), PA6 (5%, 29%) and PBT (6%, 31.5%). Similarly for flow rate the difference is PC(6.3%, 43.5%), PP(2.5%, 21.2%), PA6 (5.2, 40.8%) and PBT (6.4%, 46%).
Comparing wear in width of length for time of fill PC (6%, 16.4%), PP (2.5%, 10%), PA6 (5%, 14.5%) and PBT (6%, 15%). Similarly for flow rate the difference is PC (6.3%, 19.5%), PP (2.5%, 11.1%), PA6(5.2%, 16.9%) and PBT (6.4% 17.6%).
Comparing wear in length and depth for time of fill PC (16.4%, 30.4%), PP (10%, 17.5%), PA6 (14.5%, 29%) and PBT (15%, 31.5%). The decrease is almost double for the materials in this. Similarly for flow rate the difference is PC (19.5%, 43.5%), PP (11.1%, 21.2%), PA6 (16.9%, 40.8%) and PBT (17.6%, 46%).

5.3 Influence of wear and tear in Circular Runner

5.3.1 Effect of radial wear on time of fill and flow rate

Runner dimensions were varied, keeping the gate dimensions constant. As shown in figure 3.3 a circular gate was used. When there was wear in gates there was no effect on flow rate, but the flow rate changed when the runner was damaged. The percentage change in fill time is greater for PC followed by PP, PA6 and PBT. The difference with respect to gates is that PP becomes more sensitive than PBT. Percentage change in flow rate is from 10.4 to 17.6.

5.4 Influence of Wear and Tear in Rectangular Runners

5.4.1 Effect of wear in width on time of fill and flow rate

Wear in the width has a small effect on the time of fill and flow rate. The deviation is only 3 percent but it is difficult to rectify. The effect is the same for both PP and PA6 in terms of time of fill and flow rate. But from the figures 4.89 to 4.92 it is evident that the increase in flow rate and decrease in fill time are small compared to circular runners.

5.4.2 Effect of wear in depth on time of fill and flow rate

Wear in depth has more influence on runners. The percentage change in terms of PC is 18.5 which is more sensitive than others. They are followed by PP (16%), PA6 (13%) and PBT (11.5%). Similarly for flow rate the percentage changes are PC (22.8%), PP (19.4%), PA6 (15.3%) and PBT (13.4%).

5.4.3 Comparison of the effects in wear in width and wear in depth

Analyzing the results for both wears it is noted that the wear in depth has more influence on time of fill and flow rate. Polycarbonate is more sensitive to wear followed by PP, PA6 and PBT. For wear in the width the percentage change in time of fill varied from 1.5 to 2.1 and for flow rate 1.7 to 2.9, are small. In the case of wear in the depth percentage change in time of fill varied from 11.5 to 18.4% and for flow time it was 13.4% to 22.8%.

5.5 Comparison of Influence of Wear in Circular and Rectangular Gates

For comparing the above, results are collected for combined wear in circular gates and rectangular gates. From the results it may be stated that the influence of wear in the rectangular gates is greater. In terms of time of fill the decrease in fill time for rectangular gates is from 24% to 38.3% and for circular gates it is just 10.5% to 17.5%. The percentage change is almost double in the case of rectangular gates over circular gates. If the flow rate for rectangular gates is considered, the increase is from 31% to 68% and similarly for circular gates it is 11.7% to 21.4%. The difference is greater in this case, 200% compared to circular gates. Therefore circular gates are more sensitive to wear than rectangular gates. PBT and PC are more sensitive in both types of gates. PP is the least sensitive in both cases.

5.6 Comparison of Influence of Wear in circular runners and rectangular runners

Similar to the wear in gates, even rectangular runners are more sensitive than circular ones. The difference in percentage change in time of fill decreases as the wear increases foe circular runners is from 9 to 14.7 % and for rectangular runners 12.5 to 20%. In case of flow rate the variation is 10.4 to 17.6 for circular to 14.9 to 22.5% for rectangular runners. From the results we observe that wear of tear has more influence on PC followed by PP, PA6 and PBT.

5.7 Comparison of the Influence of Wear in Gates and Runners

Gates are considered to be more sensitive to the effects of wear when compared to runners. The results obtained for all the four materials prove that. The sensitiveness varied from material to material depending upon its rheological properties. Circular gates are more sensitive than circular runners and similarly rectangular gates over rectangular runners. Flow rate remained constant when the gates were damaged but changed when there was wear in runners.

Of all the materials used the influence of wear was least on Polypropylene for gates and PBT for runners. PP and PBT are more sensitive in case of gates and PC and PP in case of runners.

CHAPTER VI

CONCLUSIONS

In the previous chapter the effects of wear on gates and runners for different materials was discussed. From these discussions we can draw the following conclusions may be drawn.

1. It was proved that changes in gate dimensions had a greater effect than changes in runner dimensions.
2. Changes in the dimensions of rectangular gates had a stronger influence than changes in the dimensions of circular gates.
3. Changes in the dimensions of rectangular runners had a stronger influence than changes in dimensions of circular runners.
4. The effect of wear on gates and runners varied for each material. This suggests that the flow depends on rheological and thermophysical properties of the materials.
5. It is difficult to rectify effects of wear in gates and runners. Once the system becomes unbalanced, changes in the operating conditions have only a weak influence correcting the balance. Thus the mold should be sent for repair as soon as imbalance is noted.
6. Since it is difficult to rectify the effects of wear, from the results we can suggest to rebuilt the gates and runners if the deviation in time of fill and flow rate exceed the following values

   For circular gates 15 % in terms of time of fill and 20 % in terms of flow rate.

   For rectangular gates 30 % in terms of time of fill and 40 % in terms of flow rate.

For circular runners 10 % in terms of time of fill and 14 % in terms of flow rate.

For rectangular gates 15 % in terms of time of fill and 17 % in terms of flow rate.

7. Moldflow software actually improves the quality of the finished part produced with significant savings.

CHAPTER - VII

FUTURE WORK

The present study on wear and tear of runners and gates of a mold is negligible. That might suggest two things. One its not given much importance and two it is difficult to control the process. Does it reflect the attitude of the industry. May not be. As the present analysis proves that there is considerable effect from the wear and tear the first suggestion seems to fade off.

Considering its importance work should extend to other materials. A database should be created from the analysis done for different material so that it could help mold designers in designing better molds economically.

Present study was limited to circular and rectangular geometries only. Trapezoidal and half round geometries should also be included in future study considering their importance.

Since it is difficult to decide when to rebuild a mold, work should be continued in this direction so that a closer definition can be given for rebuilding the molds.

Experimental validation must be done as the study was limited to results obtained from the simulation package for Injection molding.

Further study should be done to analyze the effects of combined wear in gates and runners, i.e as the present was primarily focused on effects of individual wear. And also analysis should be done when gates and runners wear at the same time.

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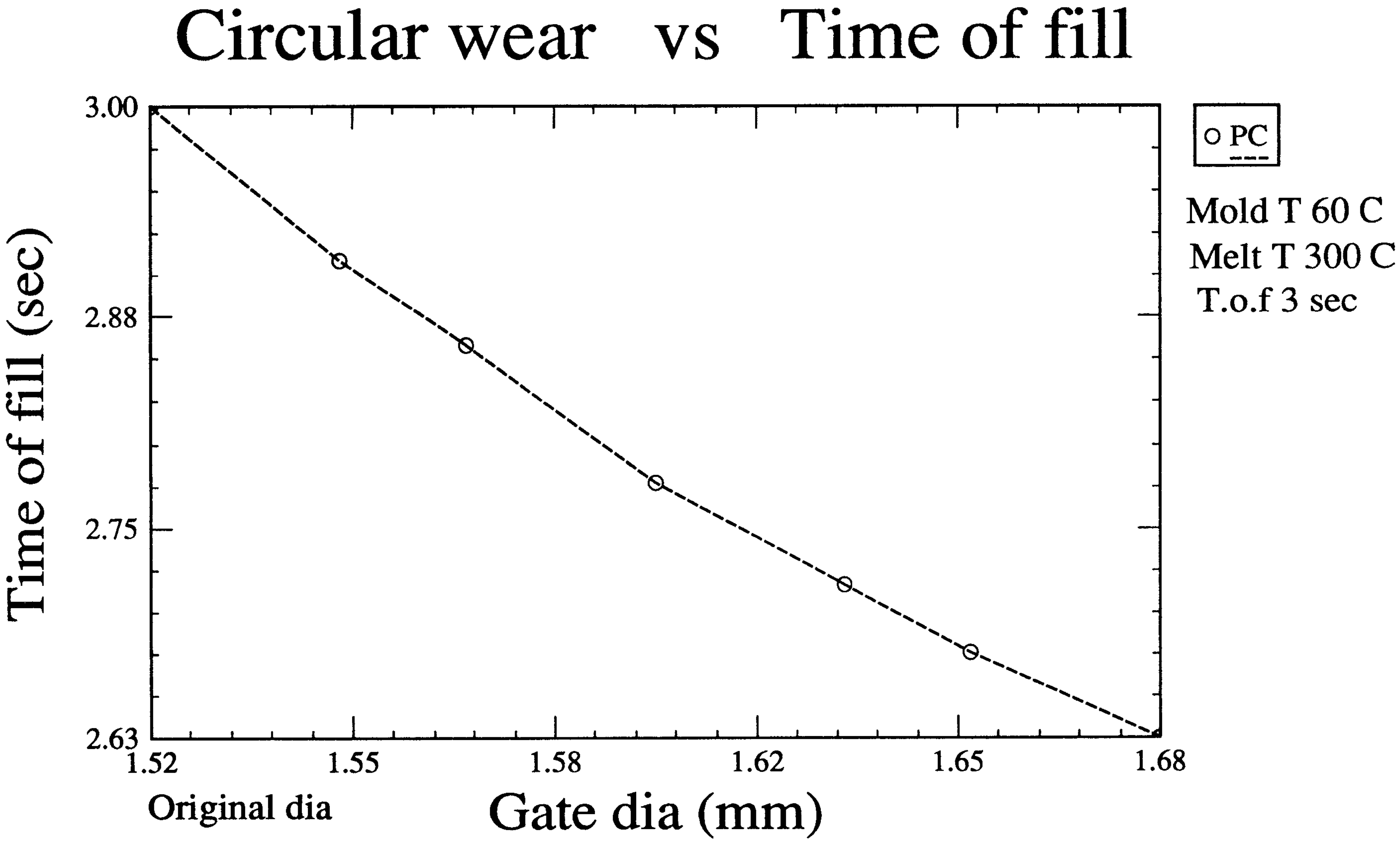

Fig. 4.1

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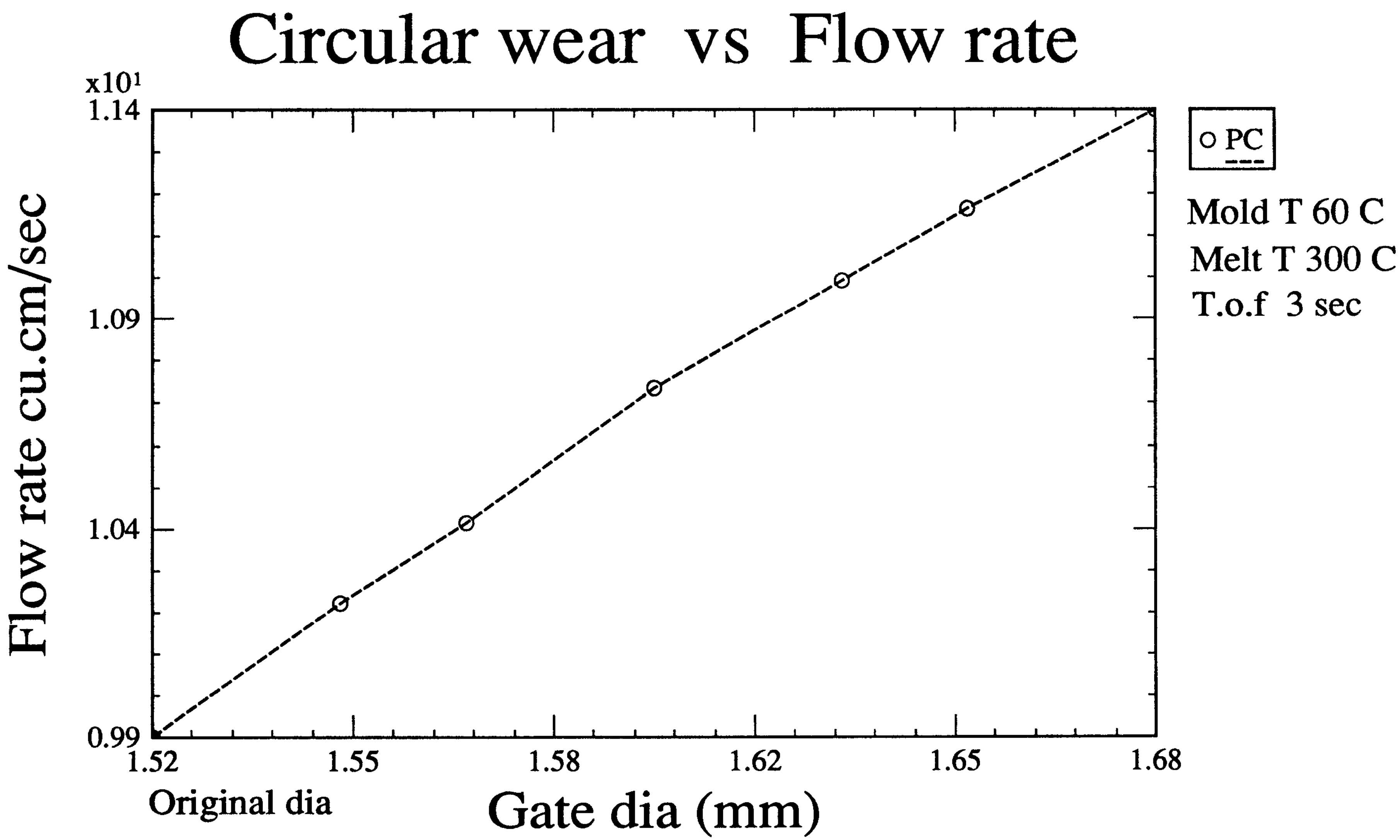

Fig. 4.2

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Wed May 1 14:58:59 1991 (data file was /usr/tmp/TG.AAAa09961)

Axial wear vs Time of fill

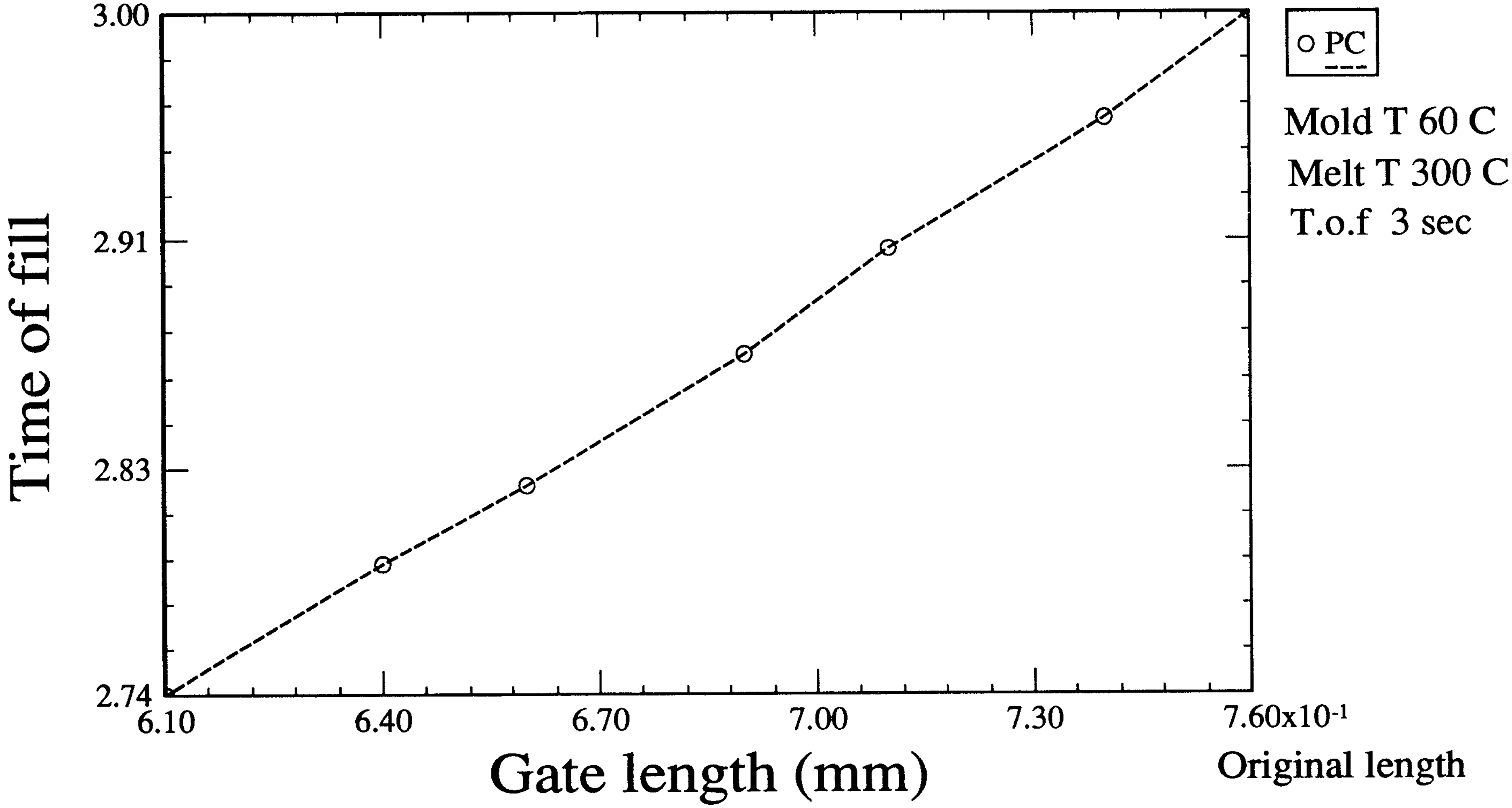

Fig. 4.3

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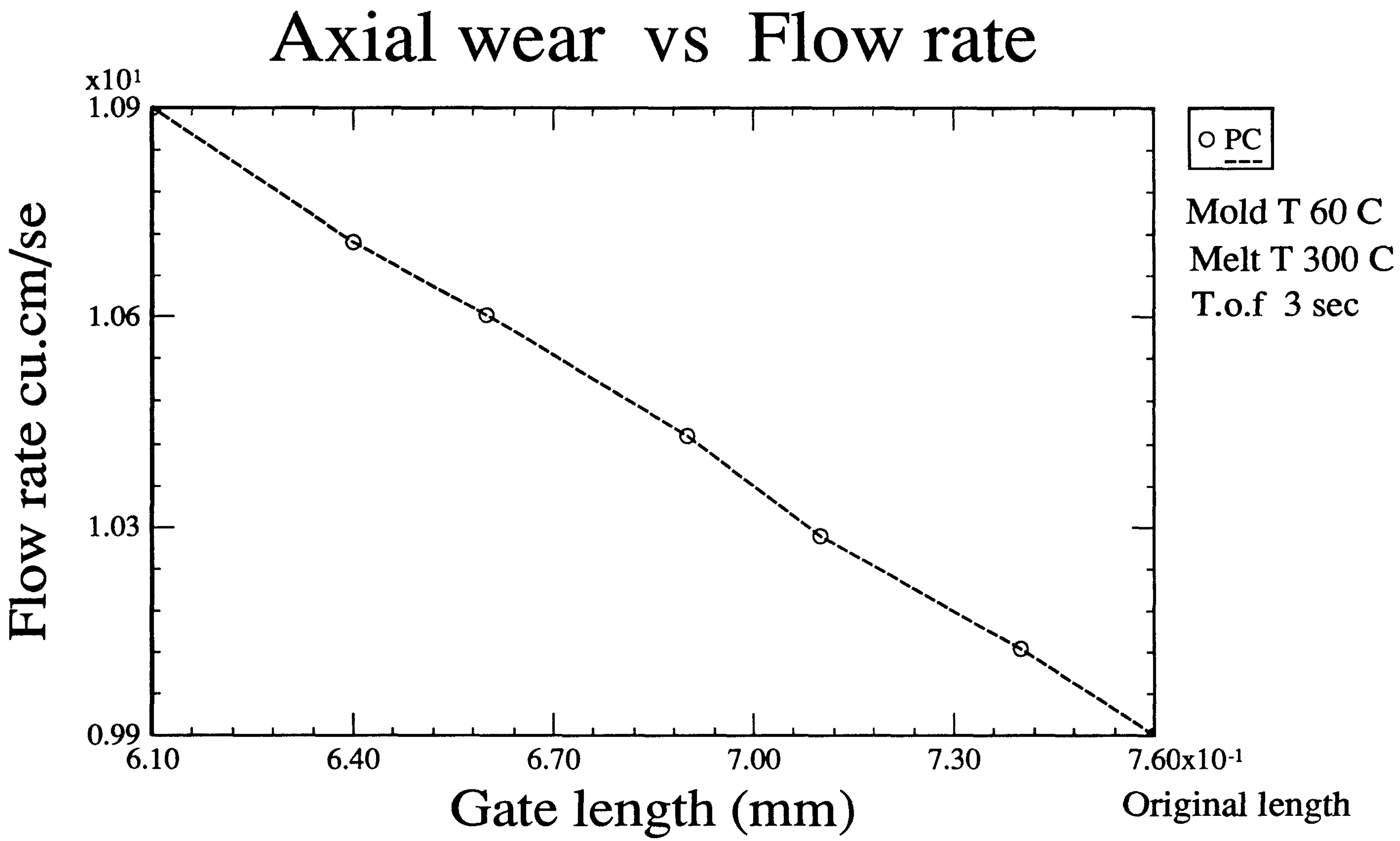

Fig. 4.4

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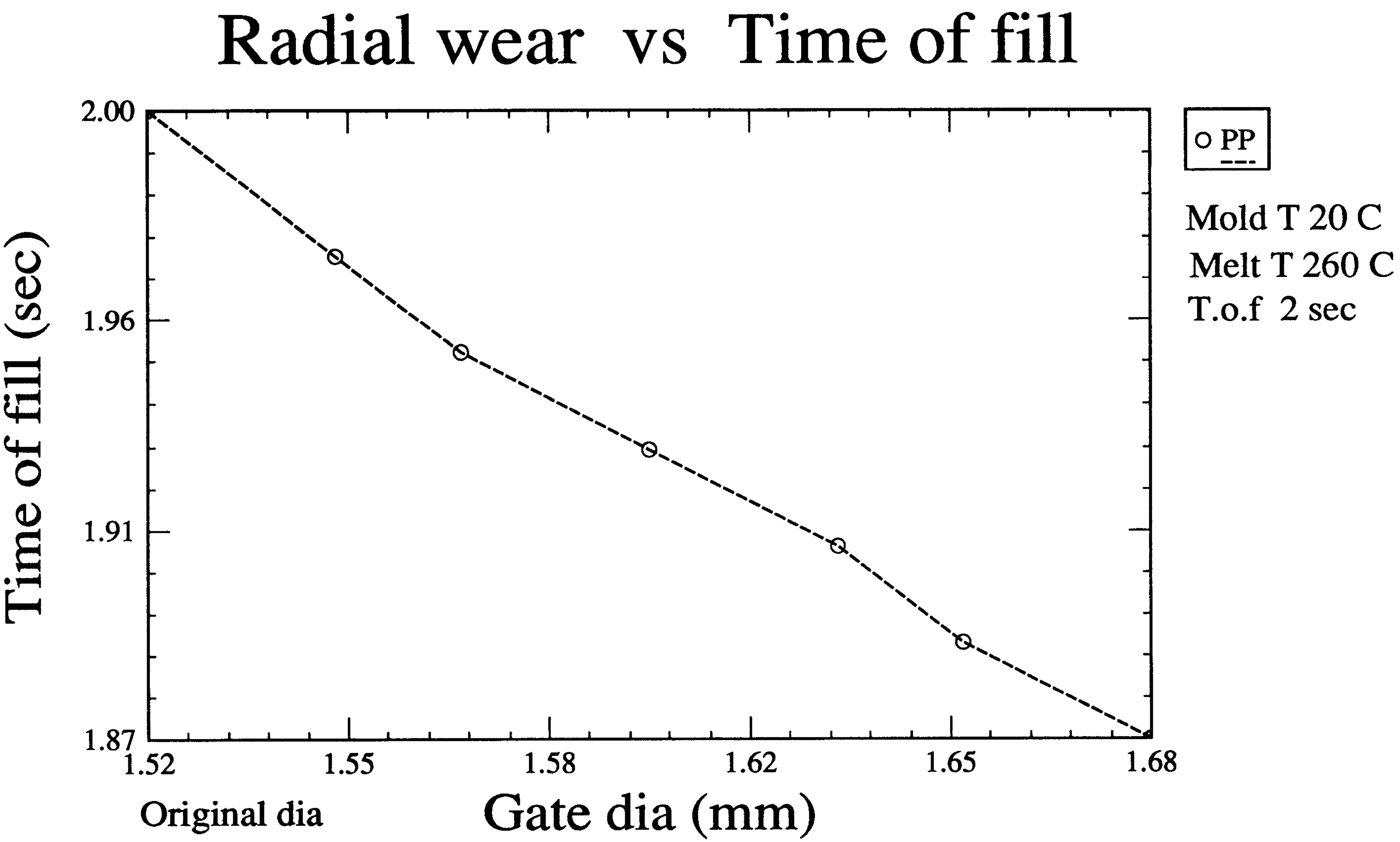

Fig. 4.5

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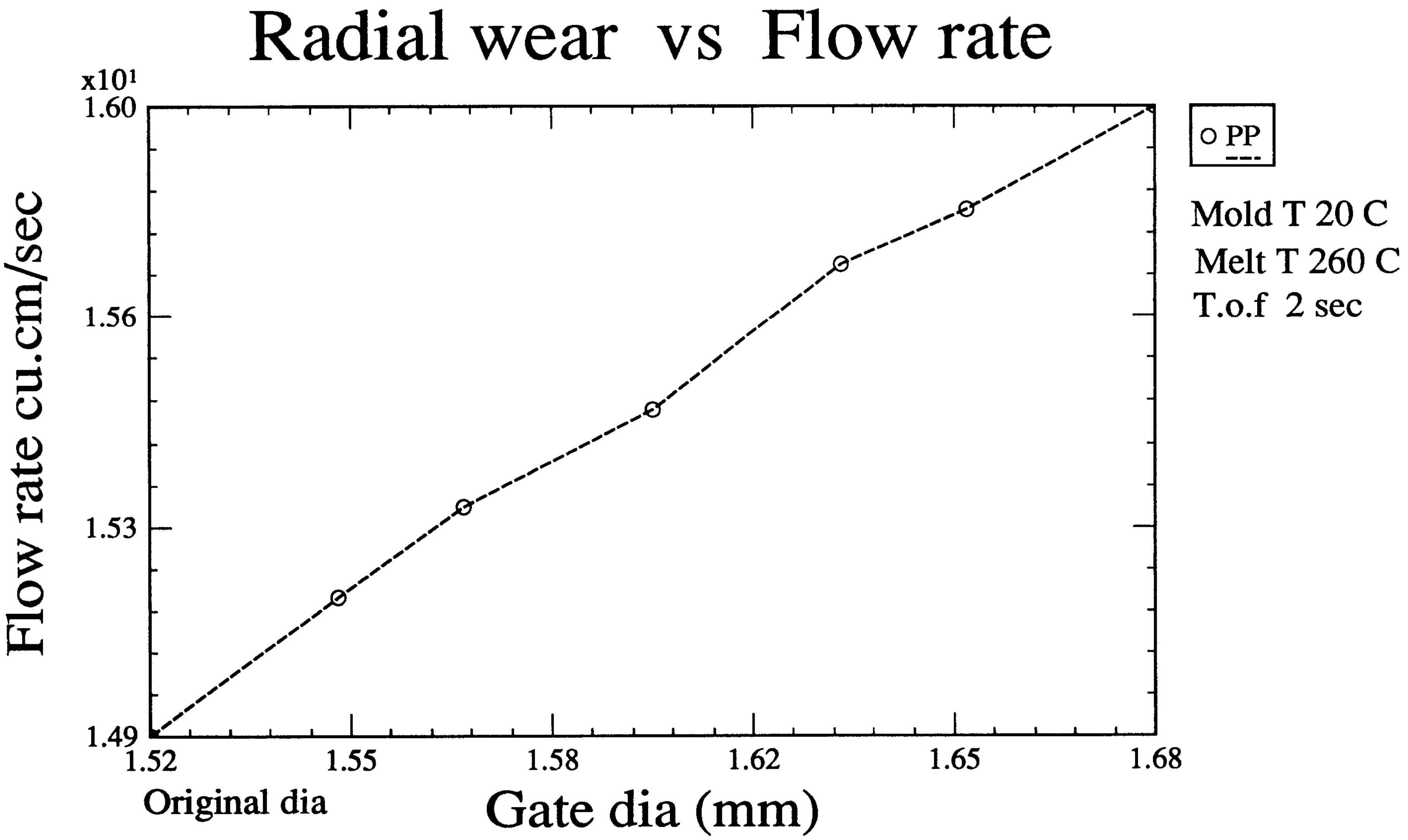

Fig. 4.6

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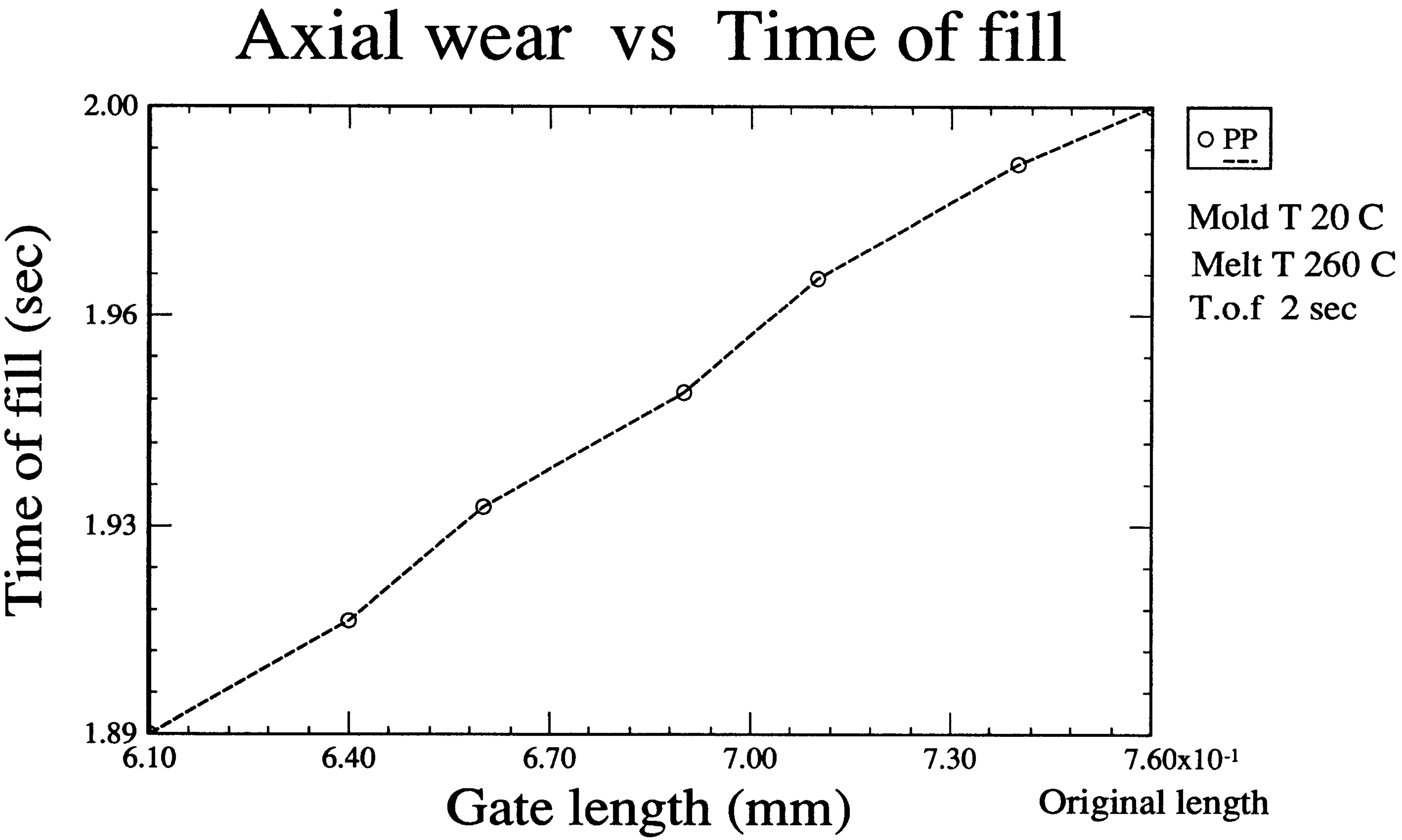

Fig. 4.7

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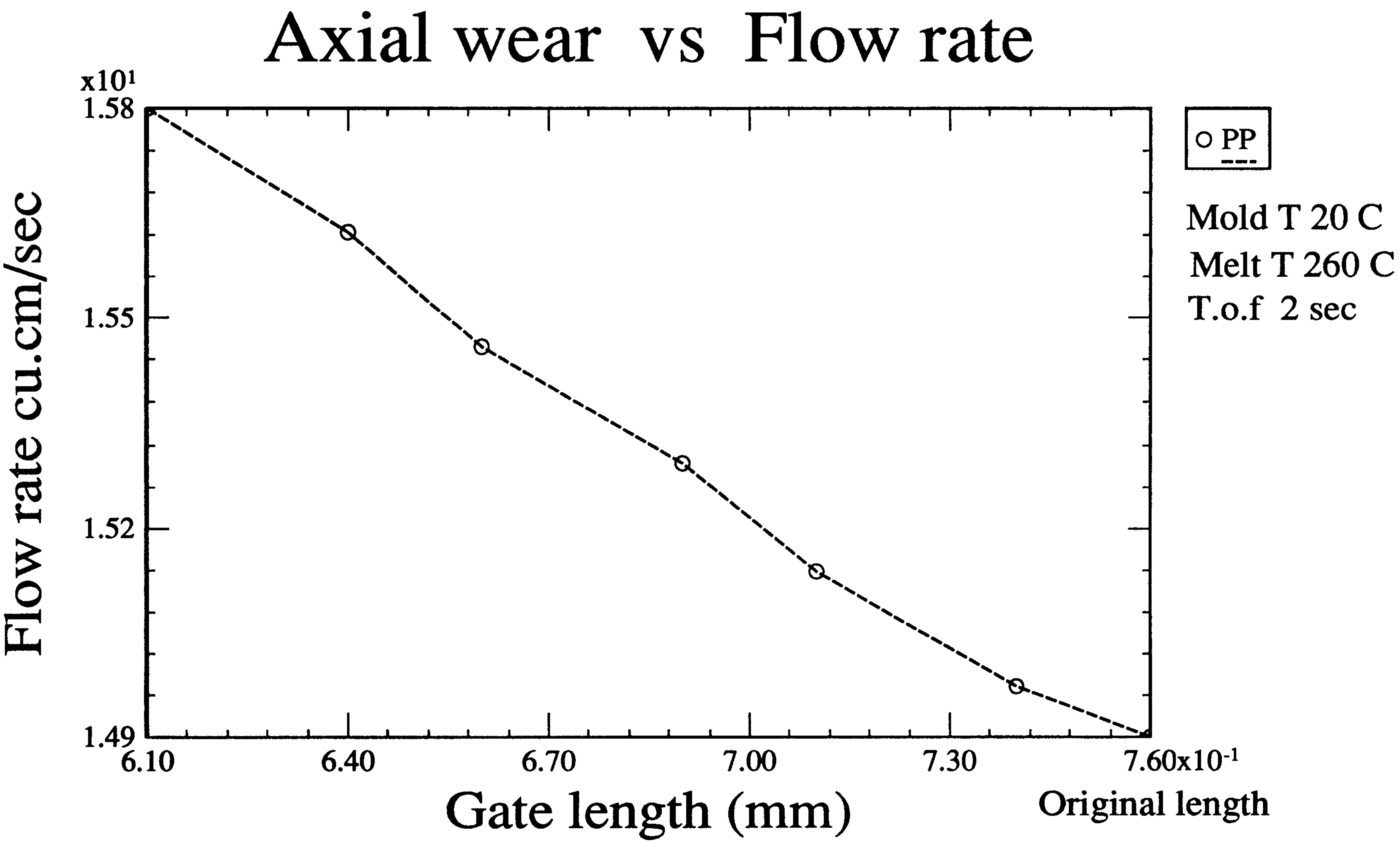

Fig. 4.8

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Radial wear vs Time of fill

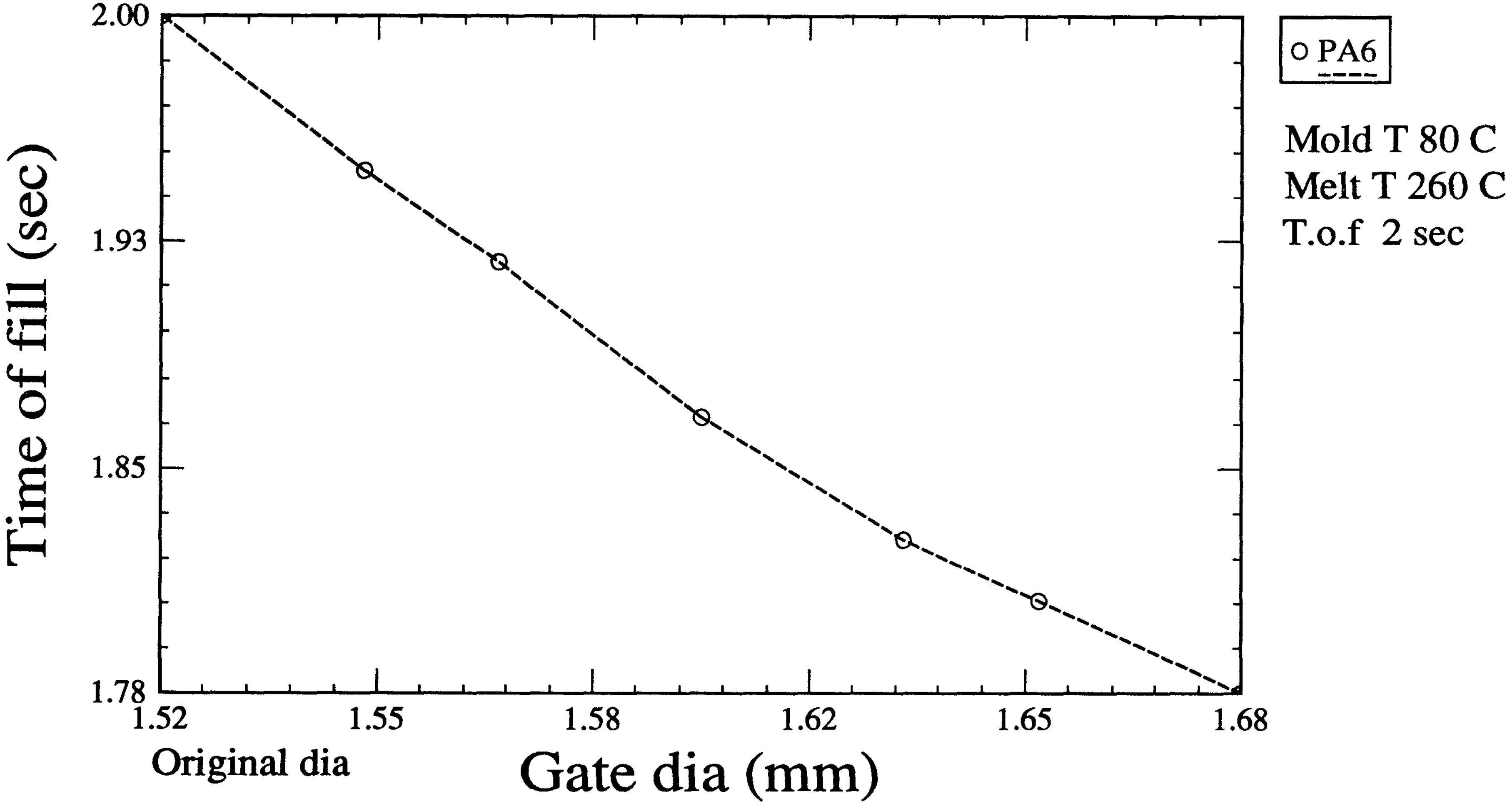

Fig. 4.9

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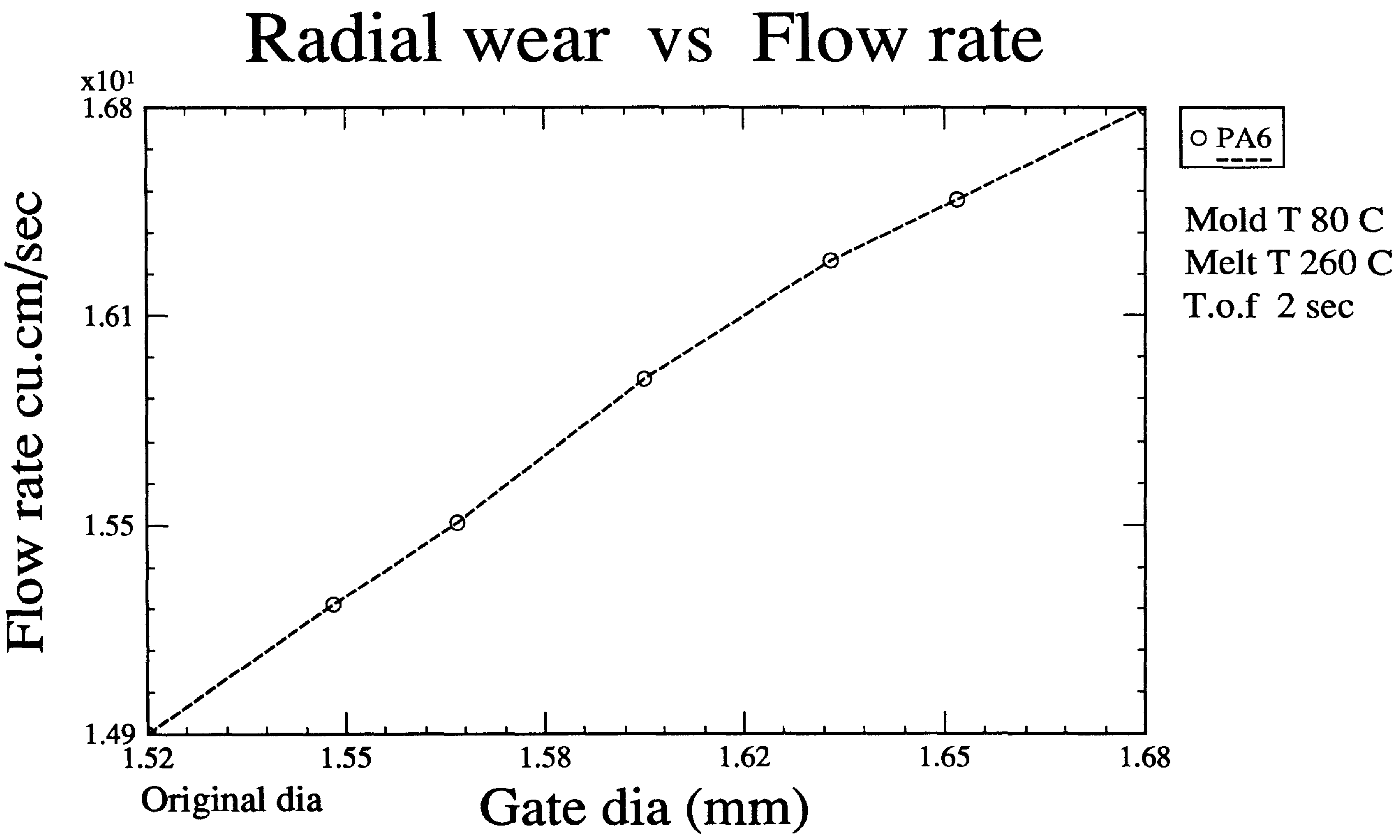

Fig. 4.10

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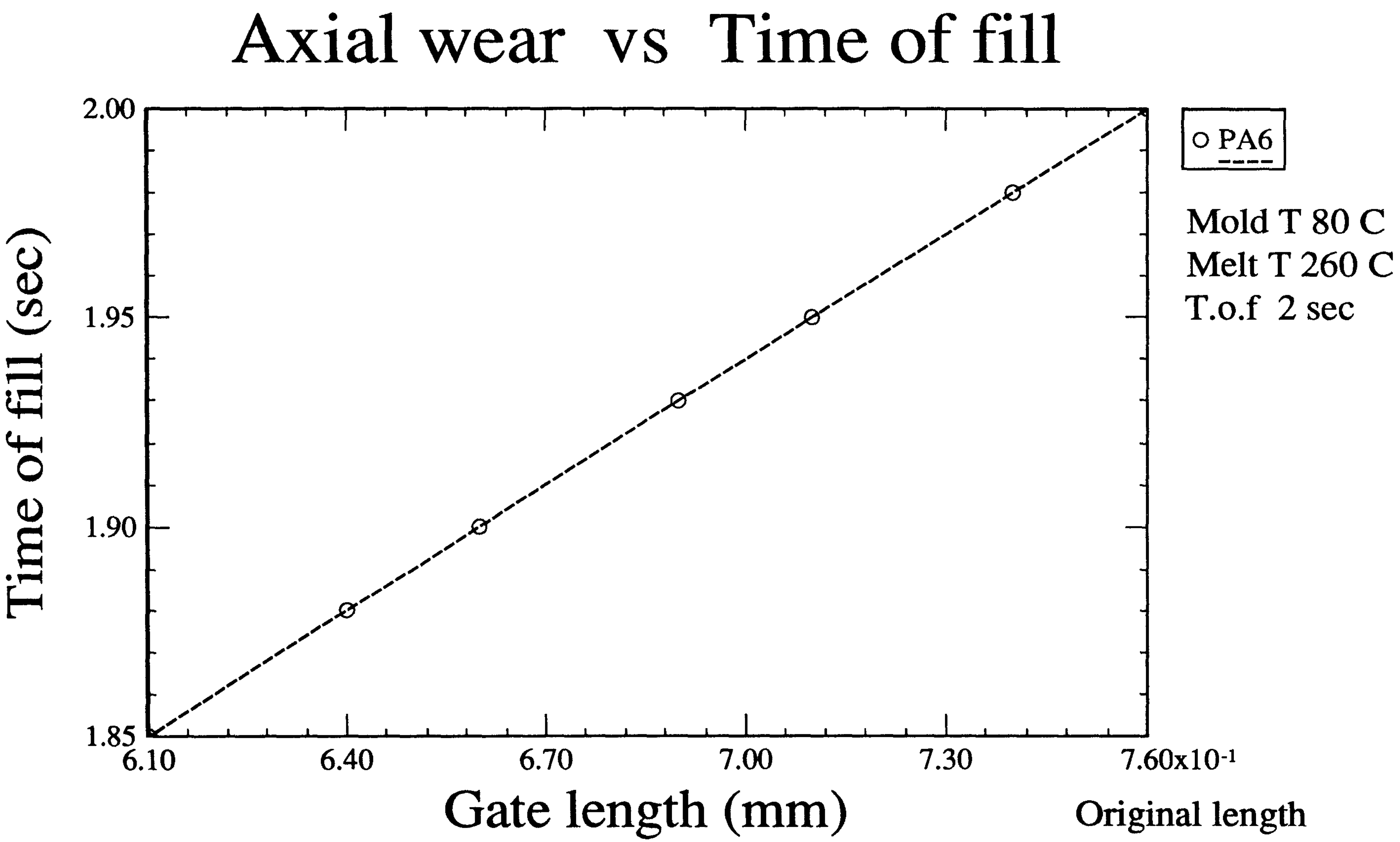

Fig. 4.11

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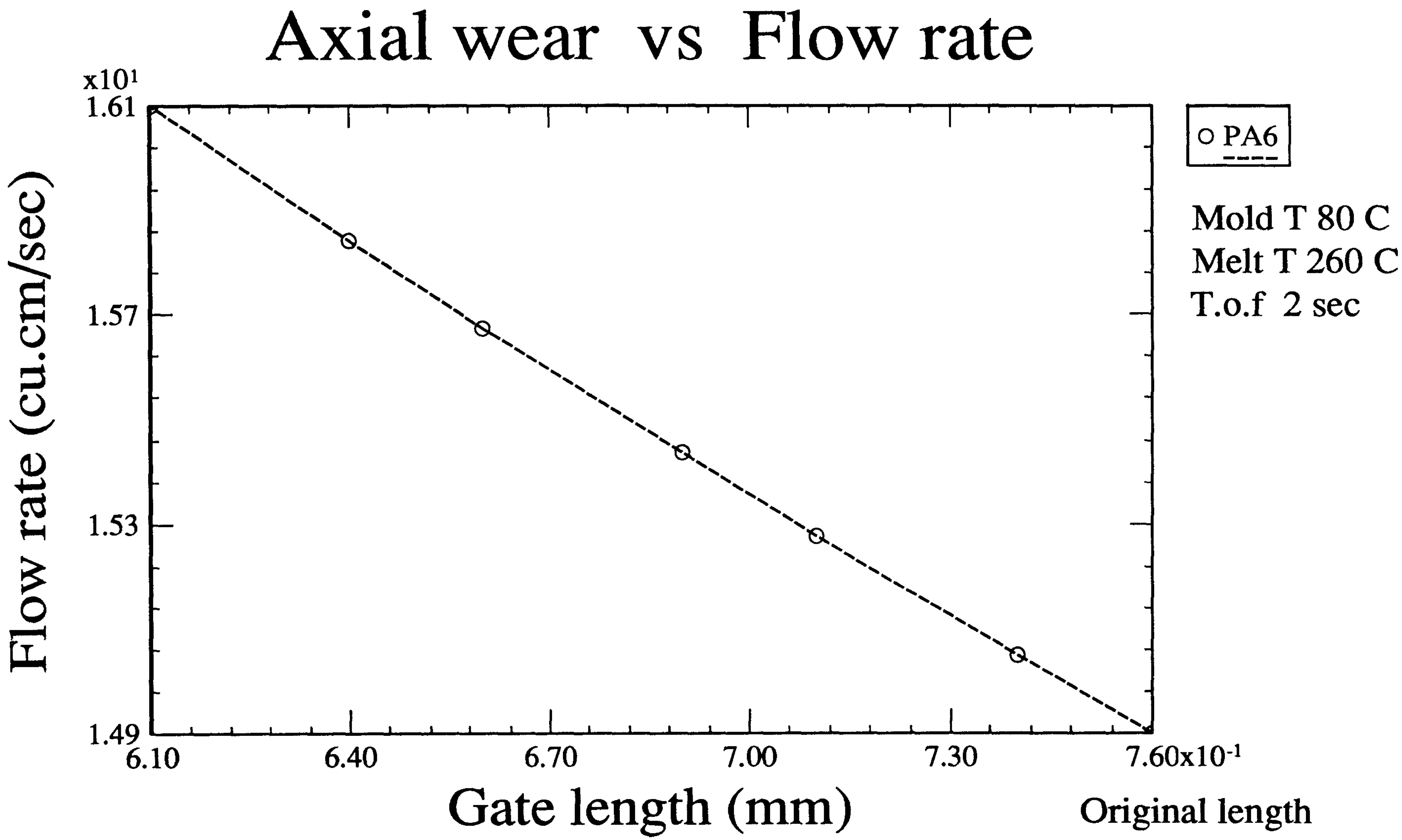

Fig. 4.12

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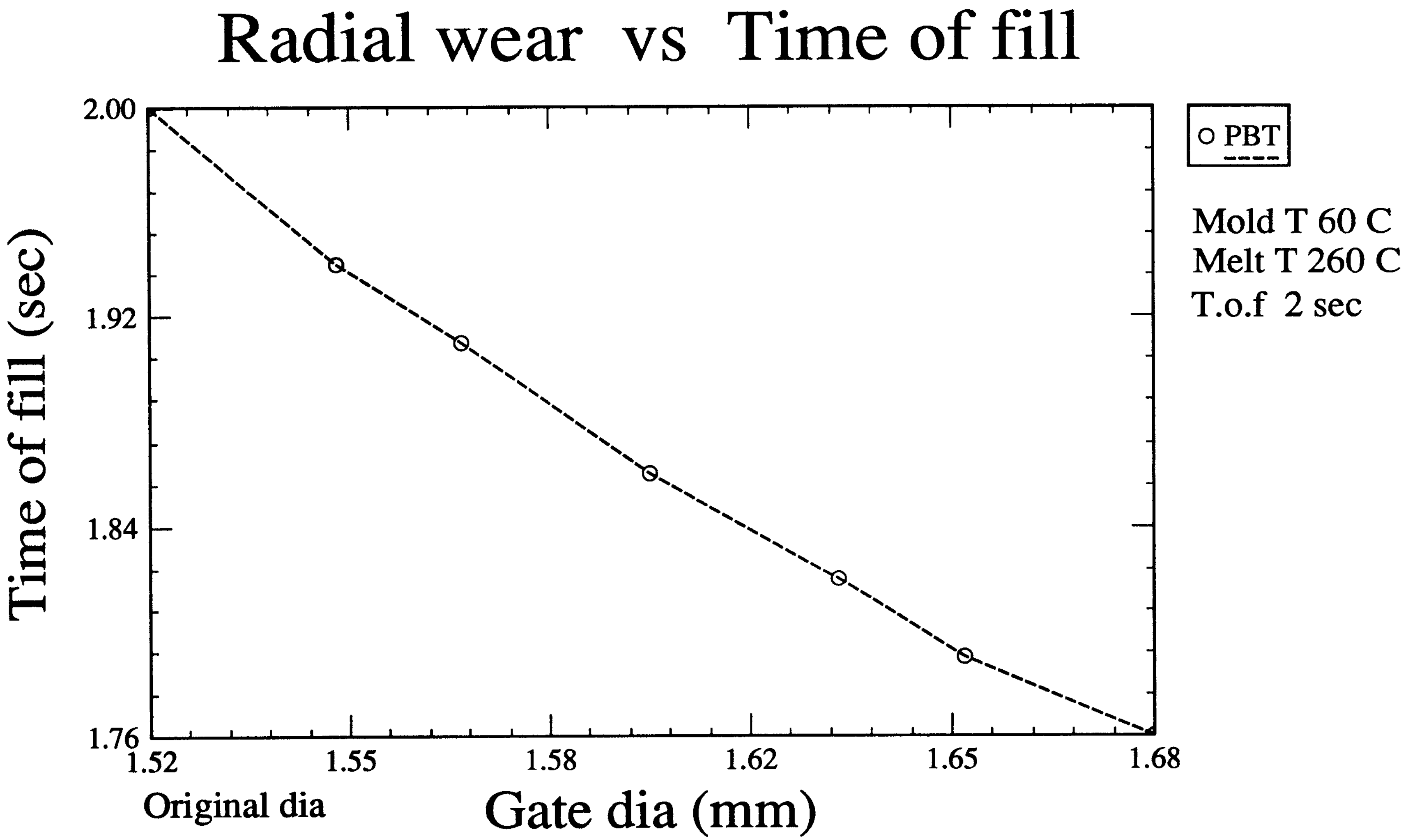

Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.13

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Wed May 1 18:50:49 1991 (data file was /usr/tmp/TG.AAAa09961)

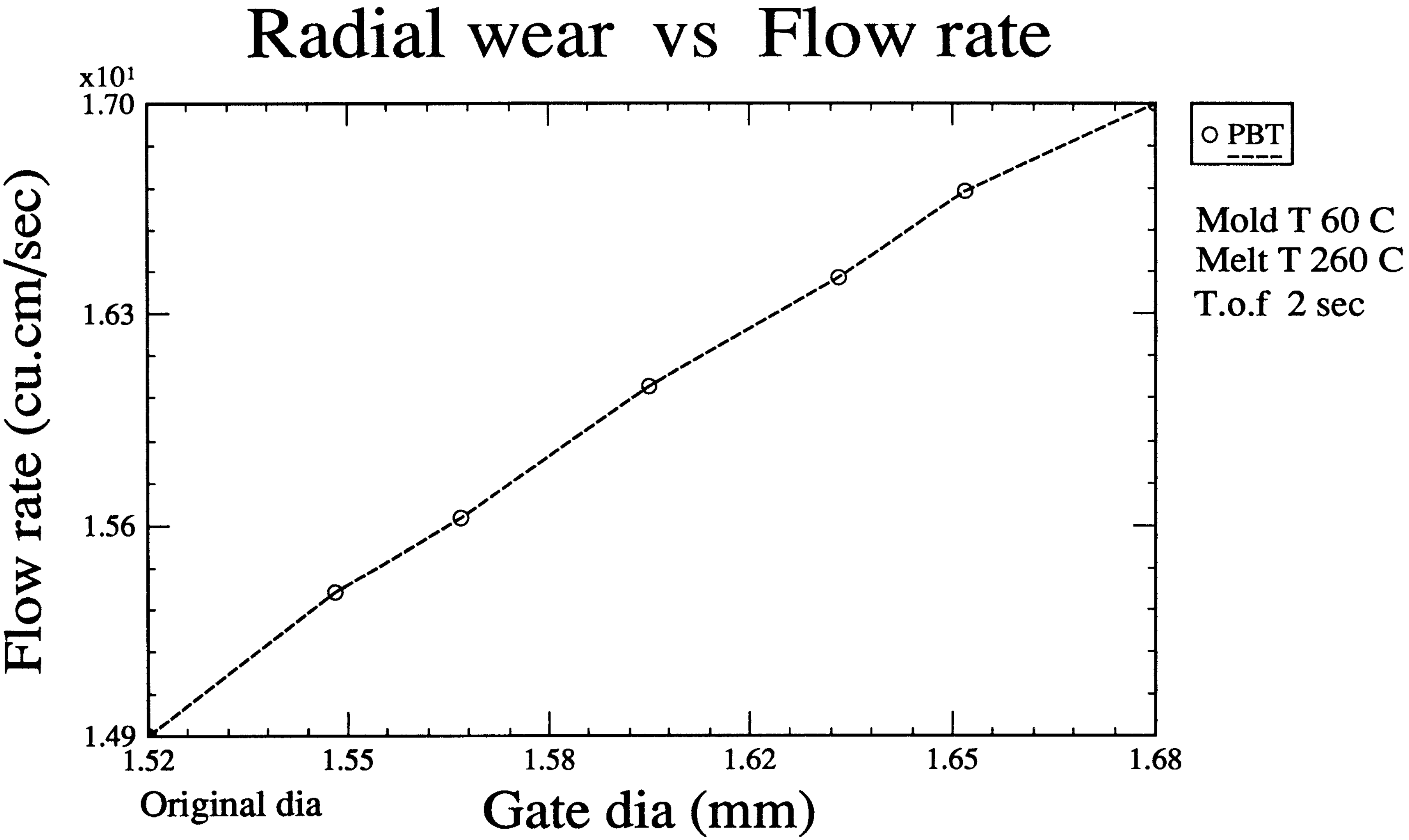

Fig. 4.14

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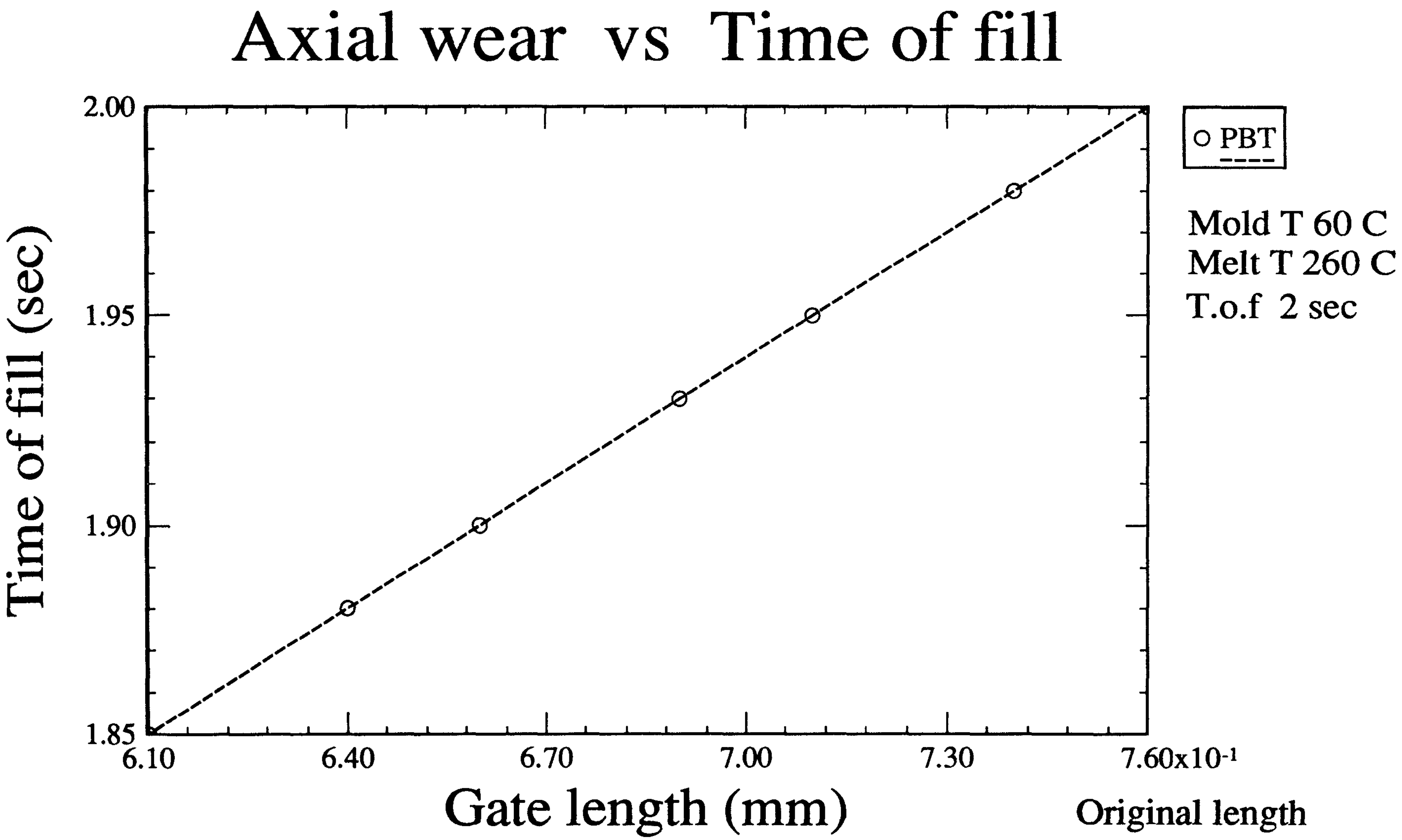

Fig. 4.15

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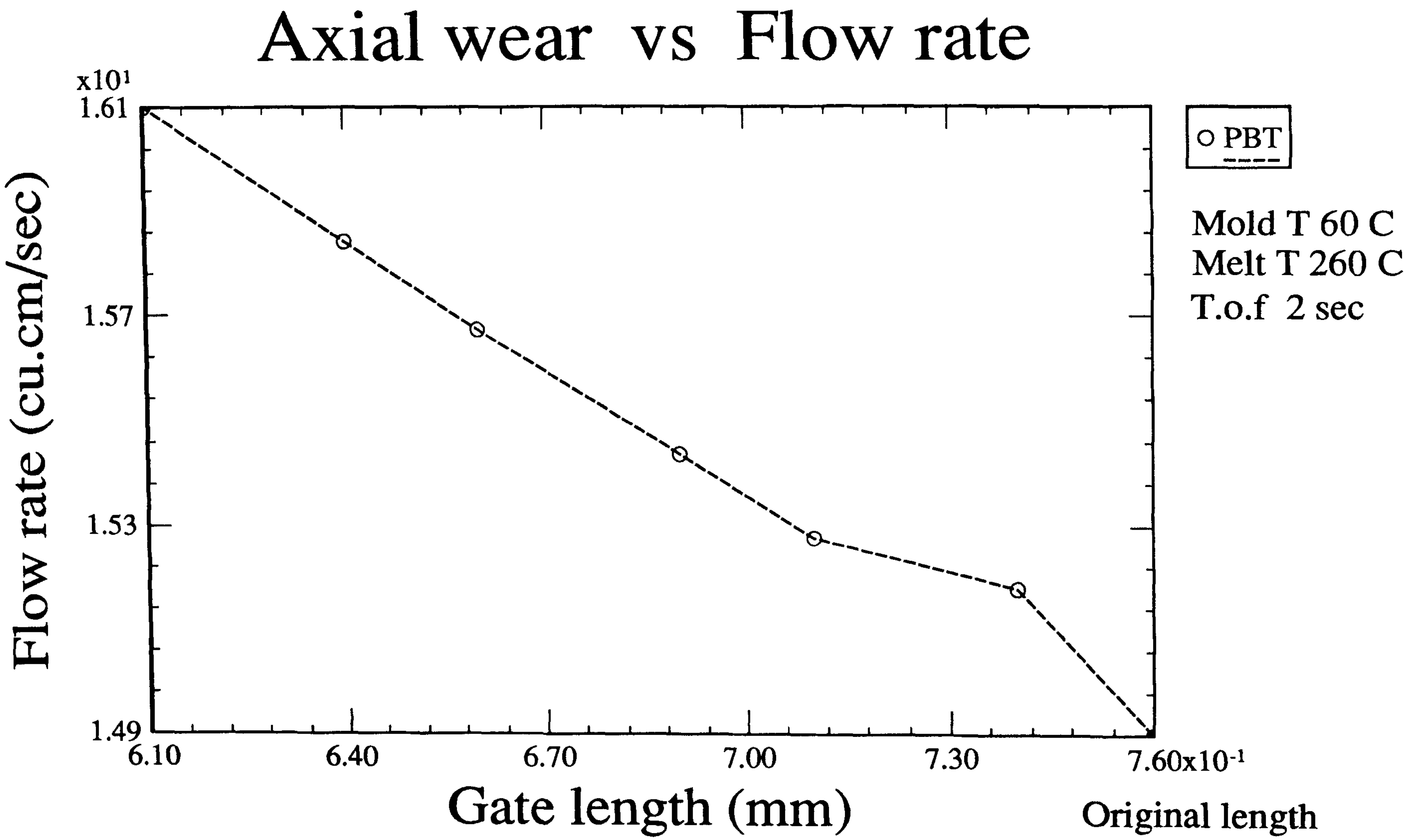

Axial wear vs Flow rate
x10¹
1.61
1.57
1.53
1.49
Flow rate (cu.cm/sec)
6.10
6.40
6.70
7.00
7.30
7.60x10⁻¹
Gate length (mm)
Original length
○ PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.16

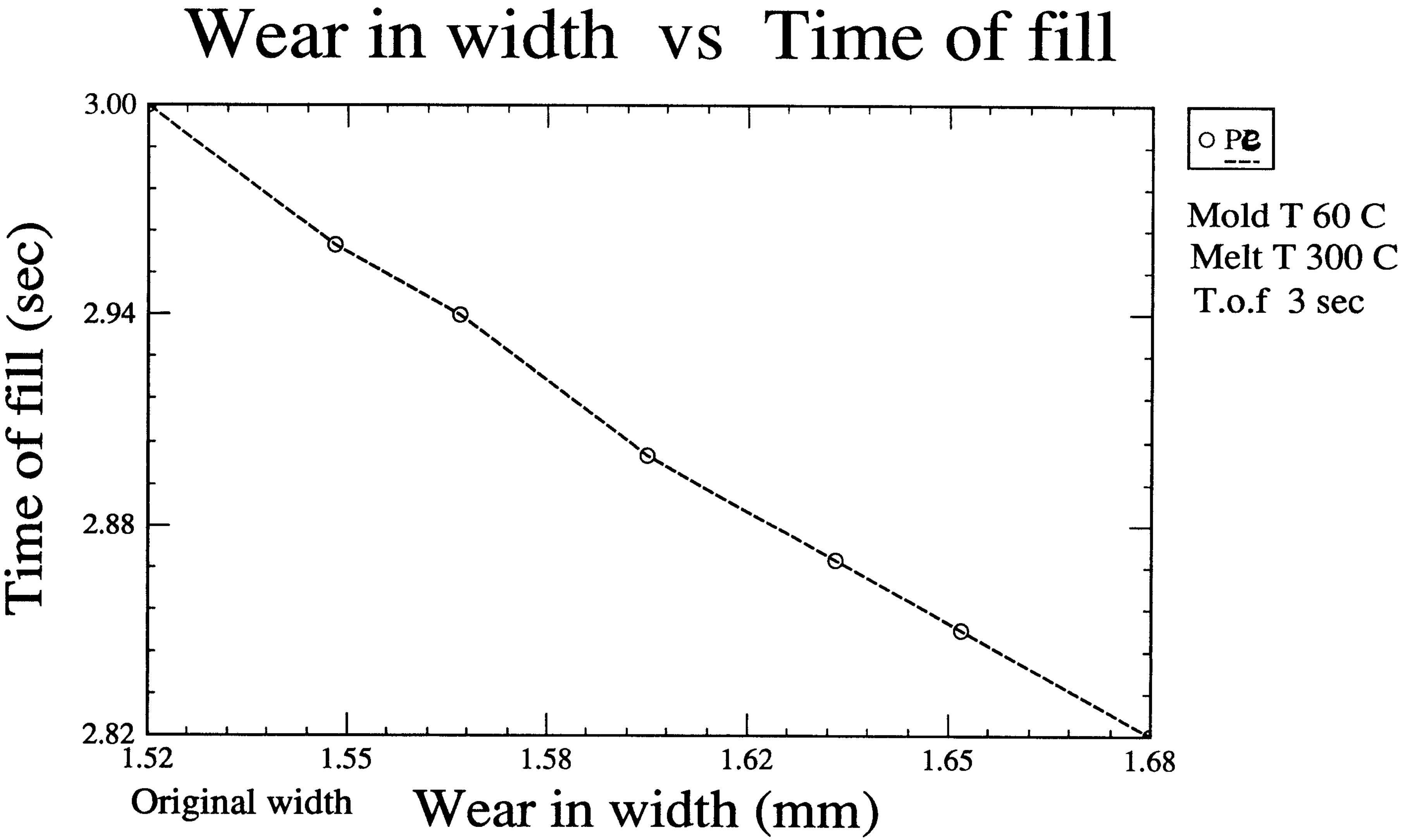

Wear in width vs Time of fill
Time of fill (sec)
3.00
2.94
2.88
2.82
1.52
1.55
1.58
1.62
1.65
1.68
Original width
Wear in width (mm)
○ PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.17

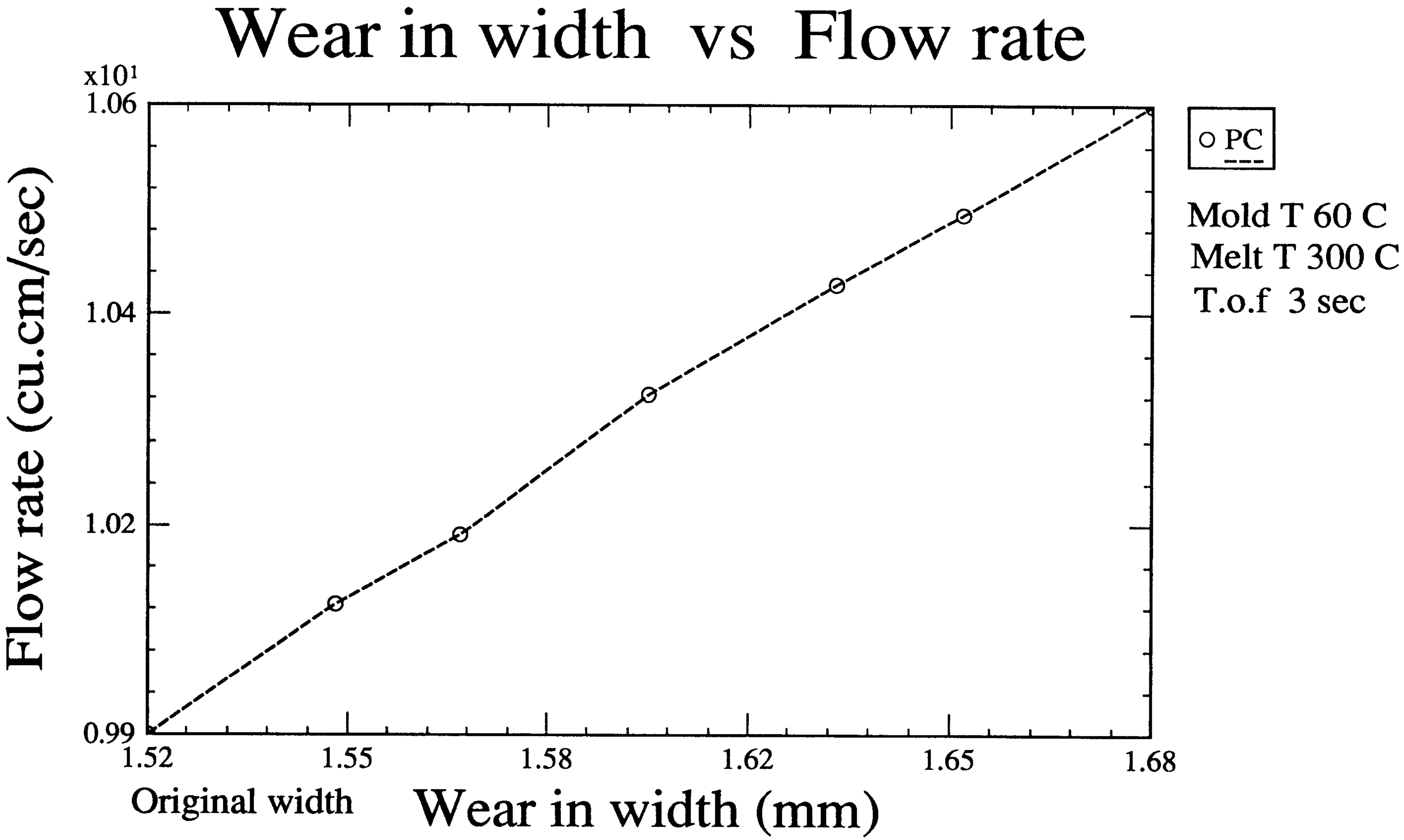


Fig. 4.18

TempleGraph 2.3 Origin: /usr/mesuna/users/rya3859@mesunw57 Fri May 3 11:47:34 1991 (data file was /usr/mesuna/users/rya3859/4.18.data)

Wear in depth vs Time of fill

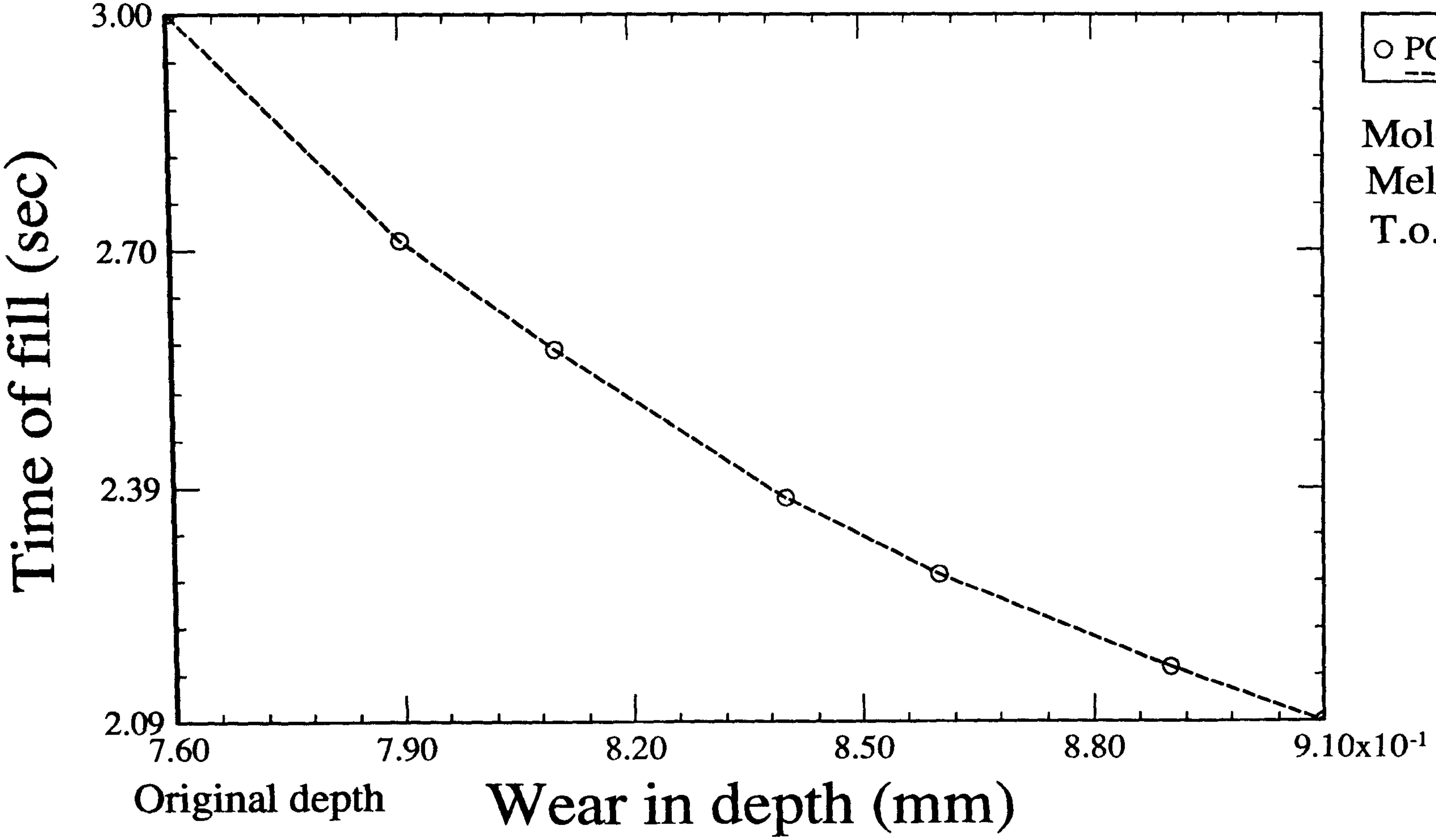


Fig. 4.19

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 12:00:29 1991 (data file was /usr/tmp/TG.AAAa15221)

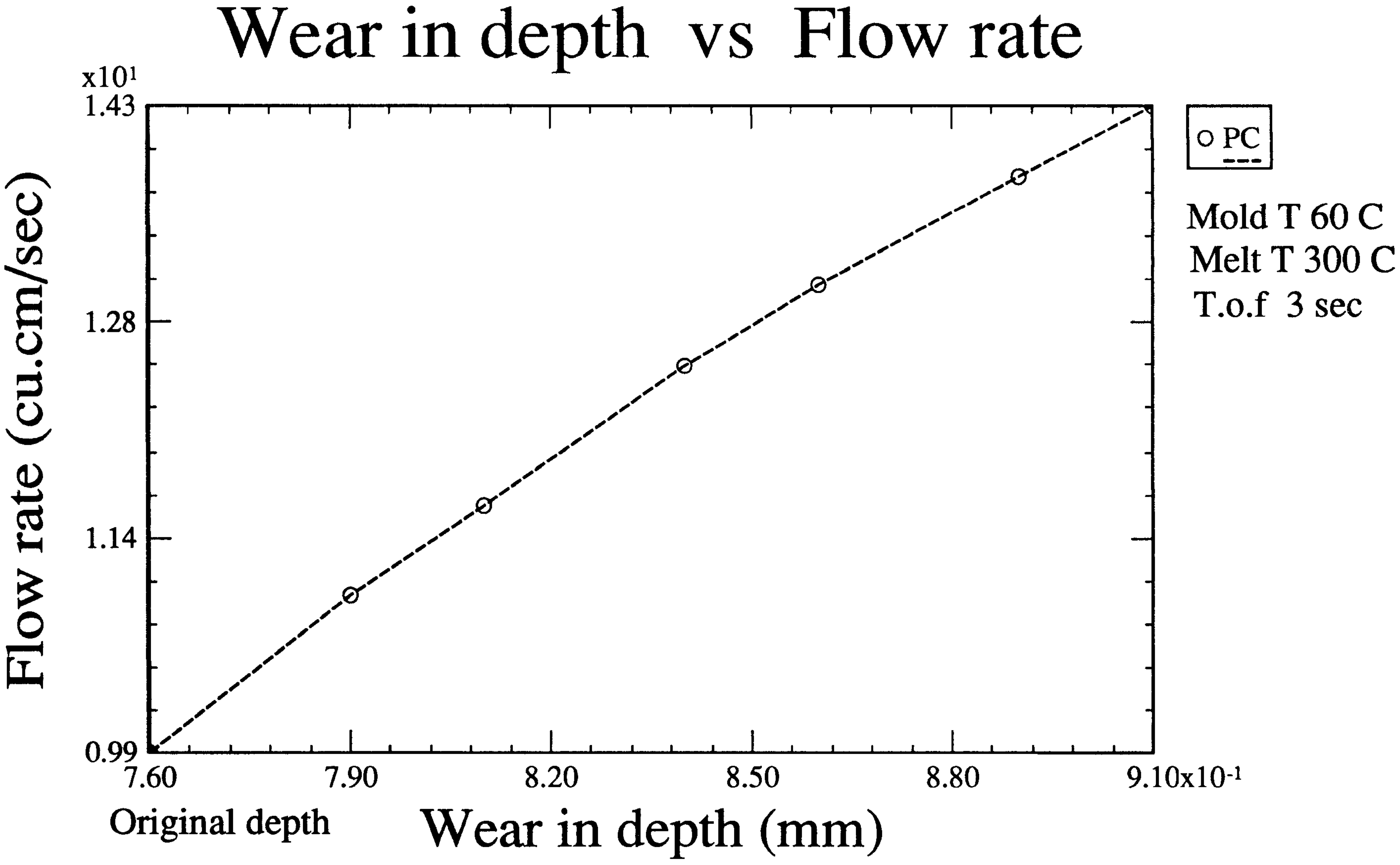


Fig. 4.20

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 11:53:11 1991 (data file was /usr/tmp/TG.AAAa15221)

Weear in length vs Time of fill

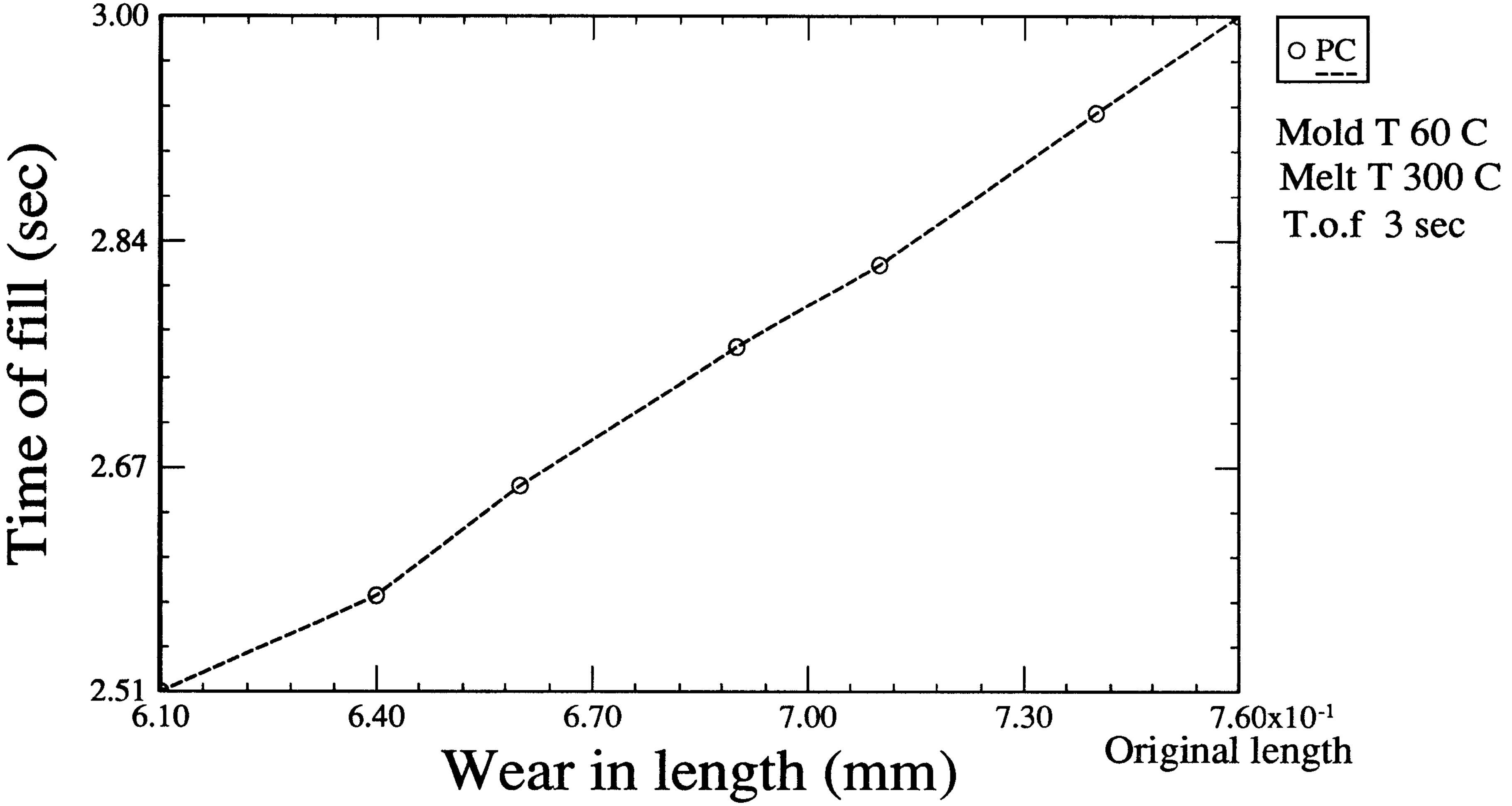


Fig. 4.21

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 12:06:09 1991 (data file was /usr/tmp/TG.AAAa15221)

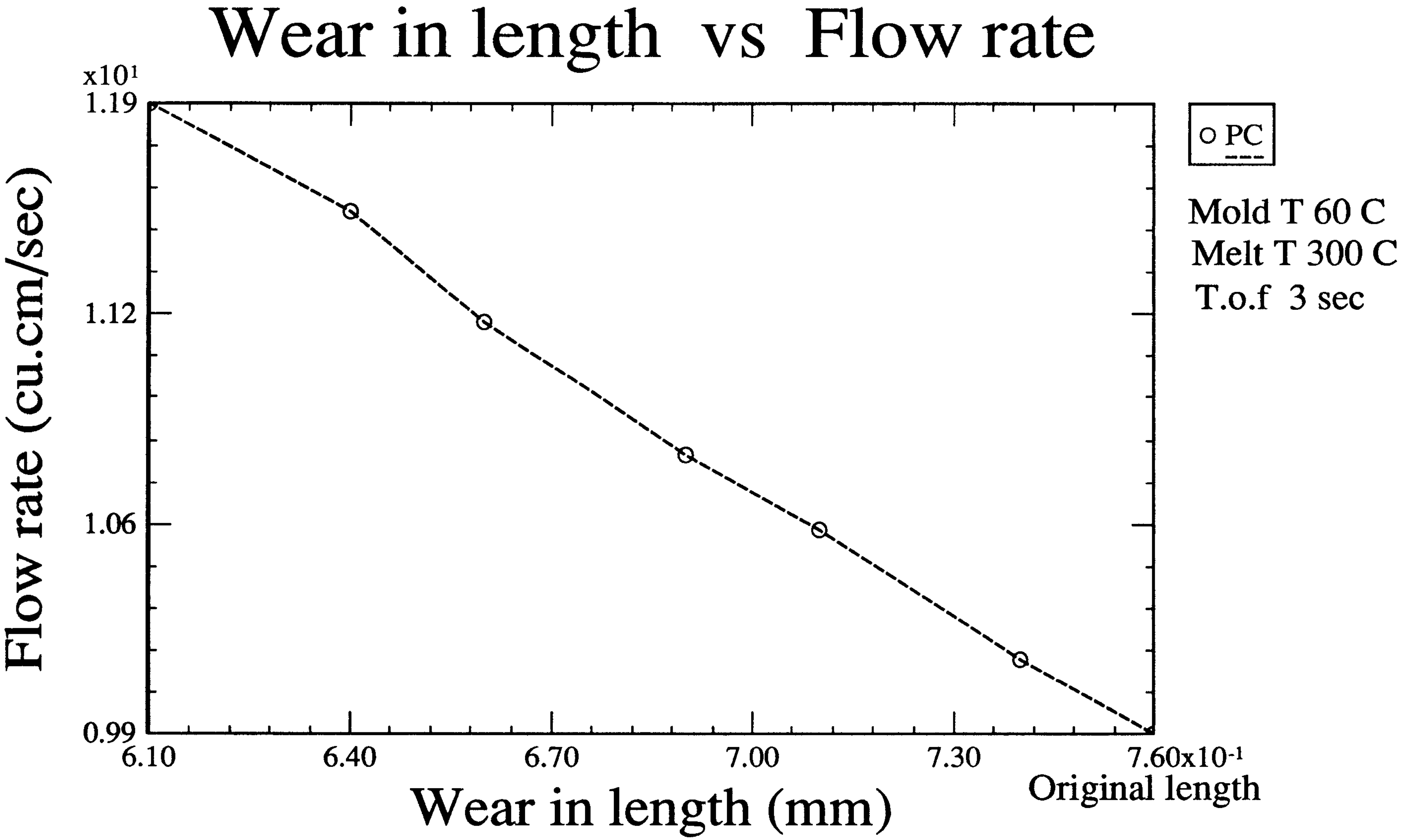


Fig. 4.22

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 12:10:55 1991 (data file was /usr/tmp/TG.AAAa15221)

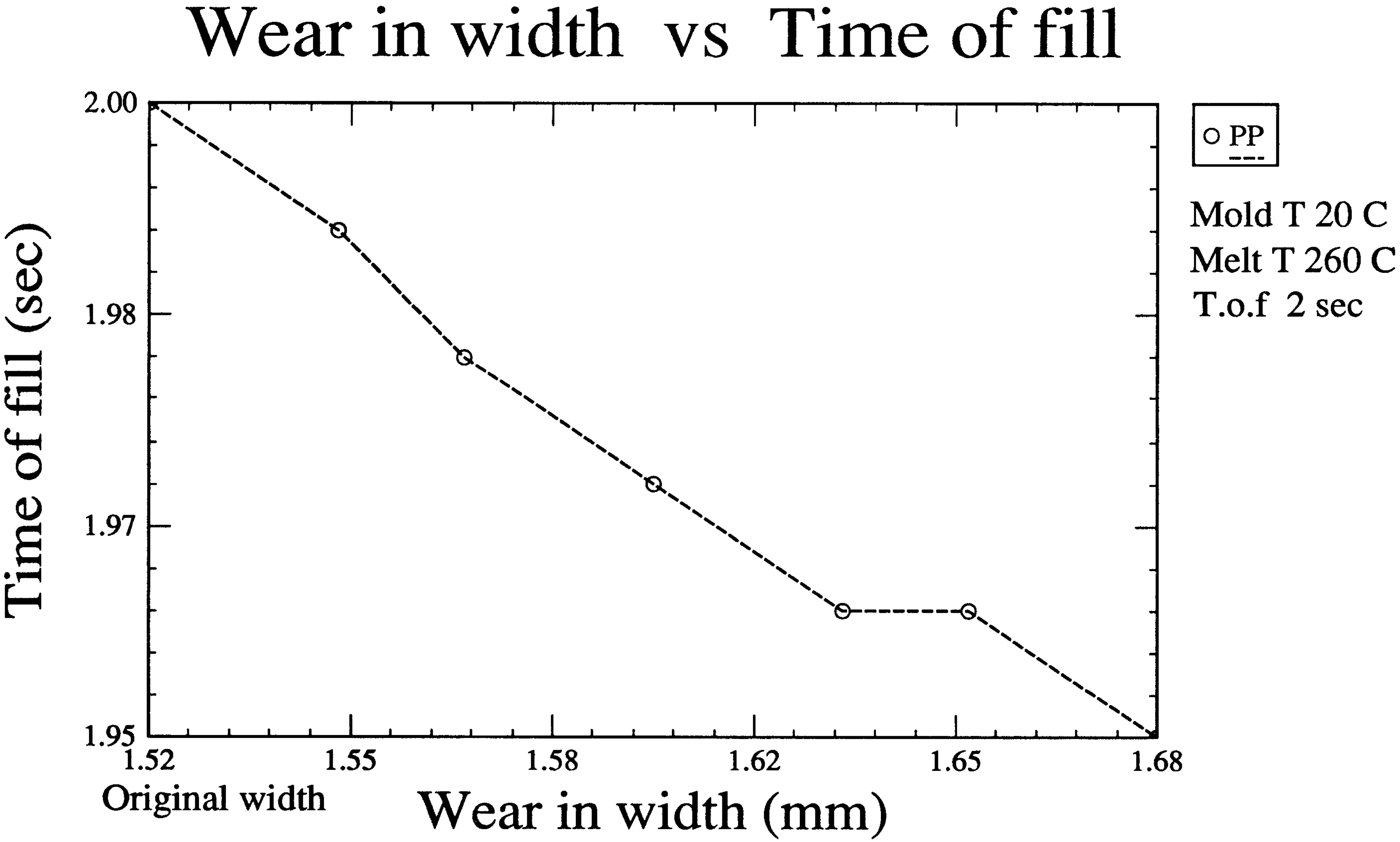


Fig. 4.23

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw61 - Fri May 3 01:24:33 1991 (data file was /usr/tmp/TG.AAAa03142)

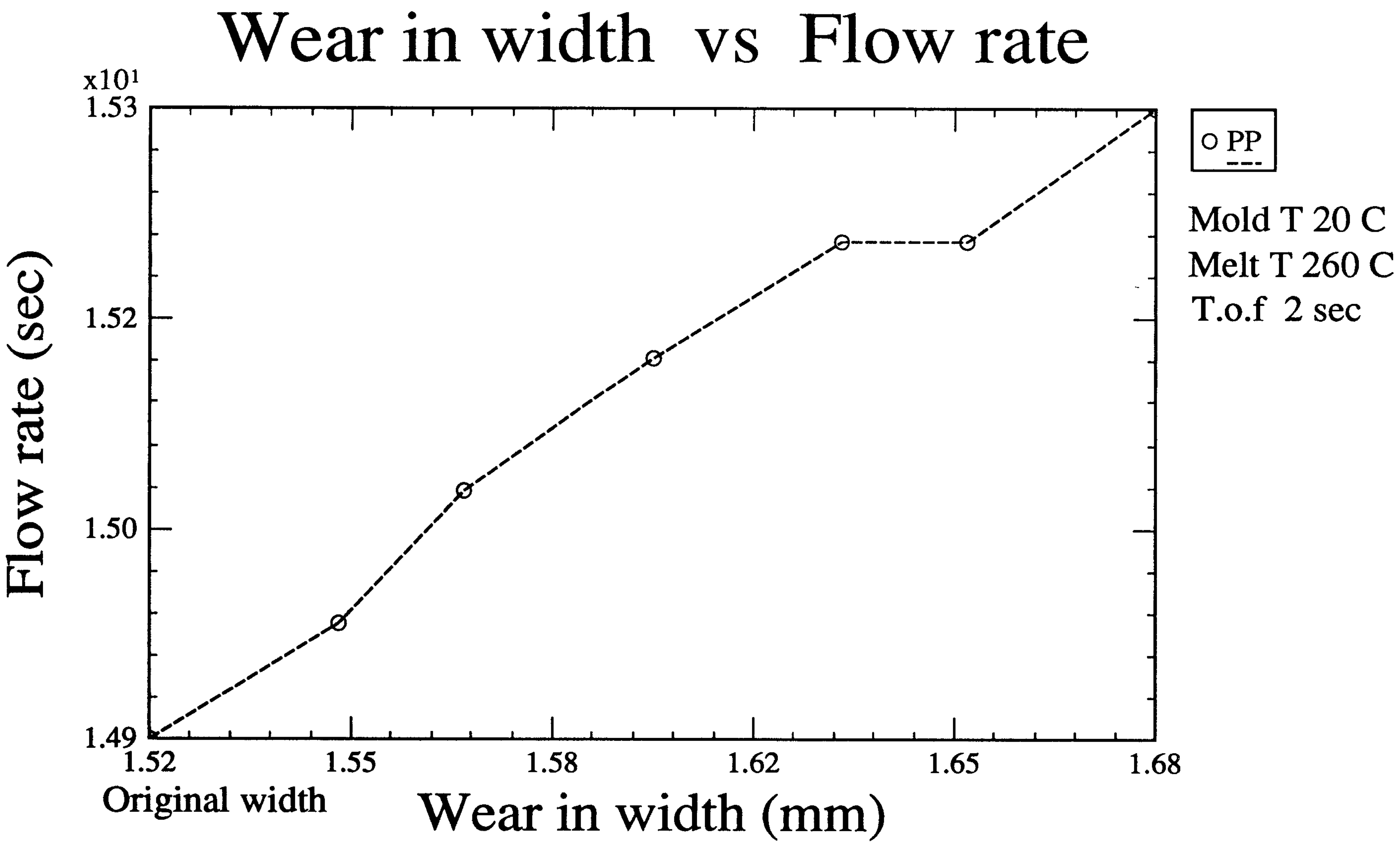


Fig. 4.24

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw61 - Fri May 3 01:30:30 1991 (data file was /usr/tmp/TG.AAAa03142)

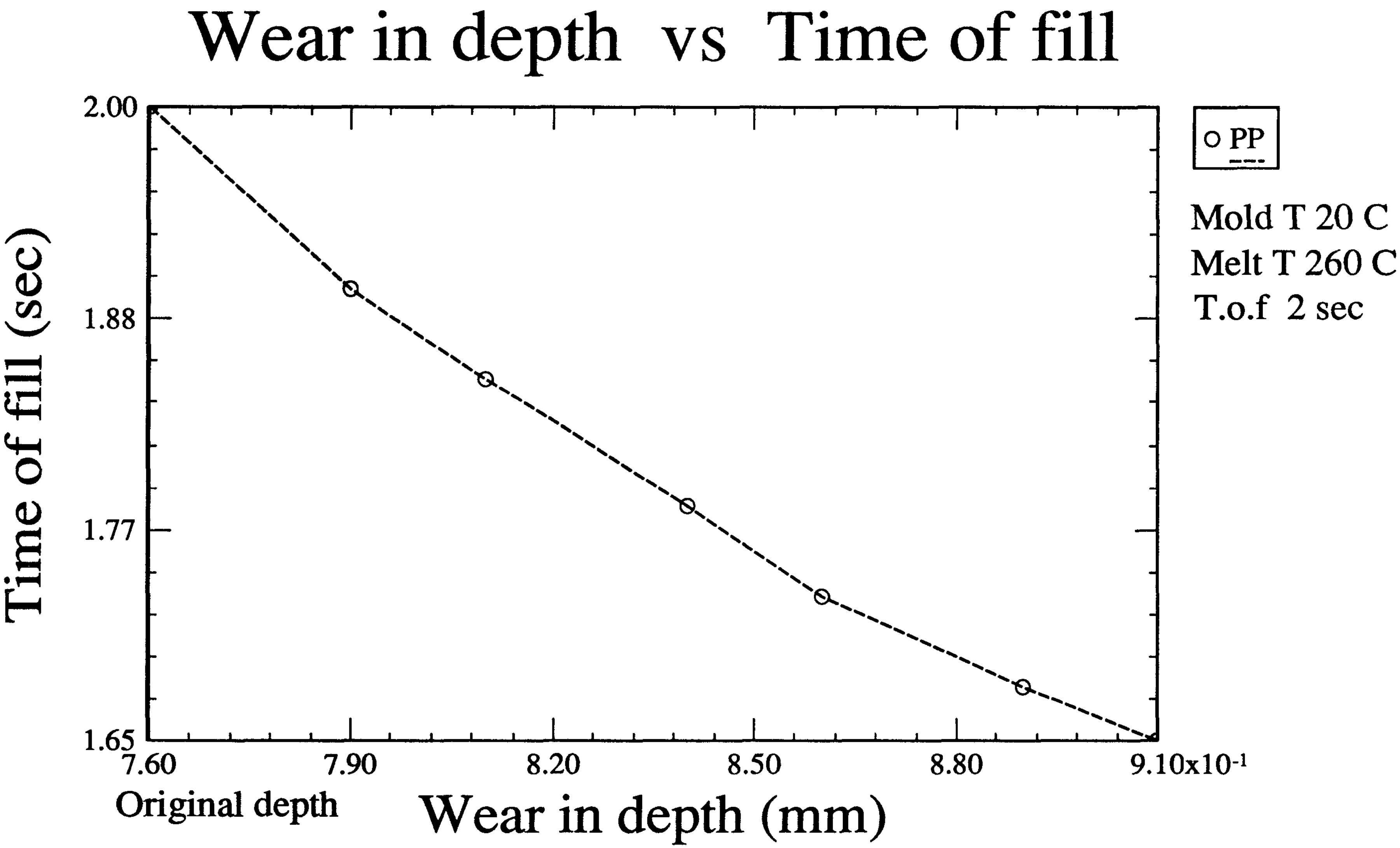


Fig. 4.25

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw61 - Fri May 3 00:16:32 1991 (data file was /usr/tmp/TG.AAAa03142)

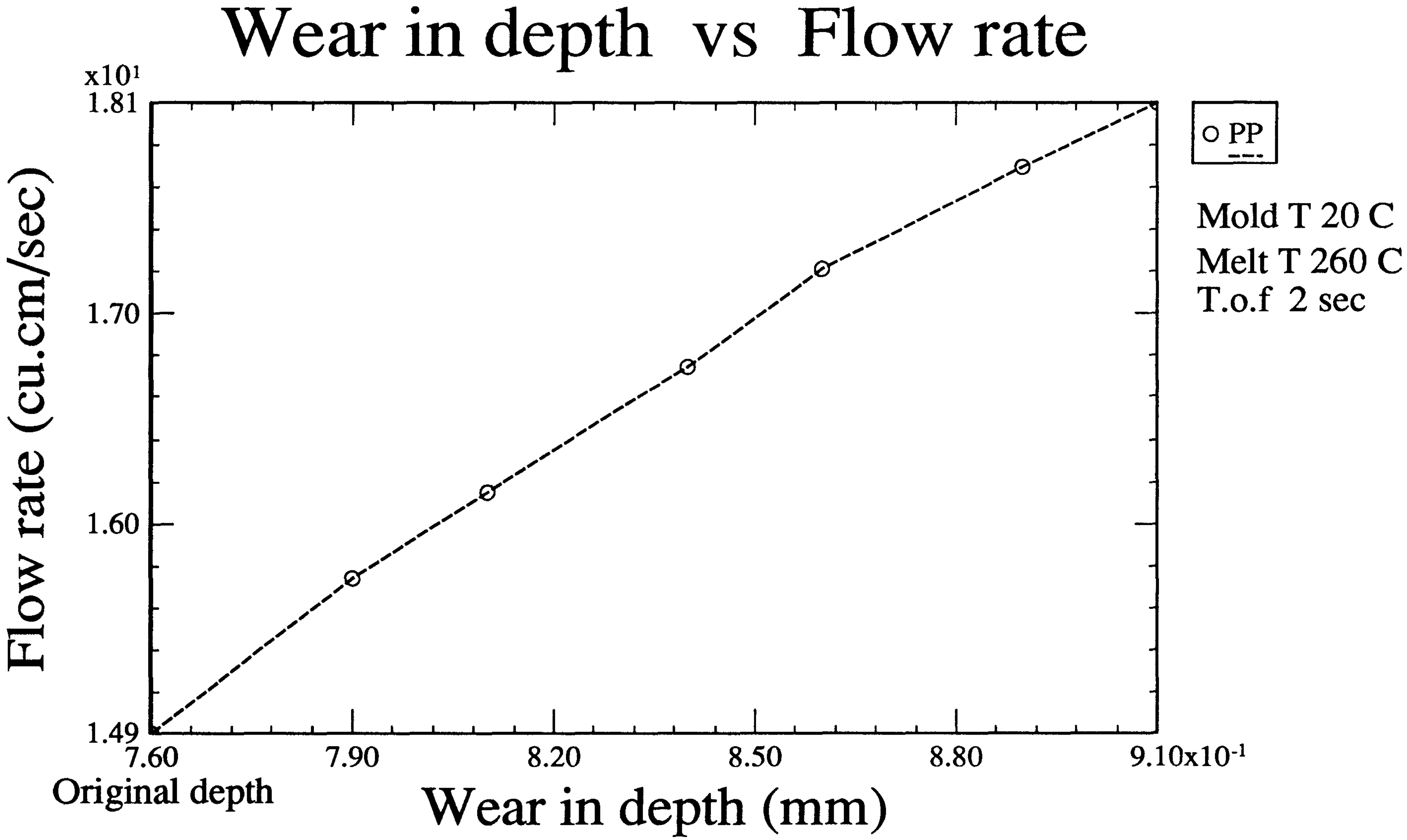
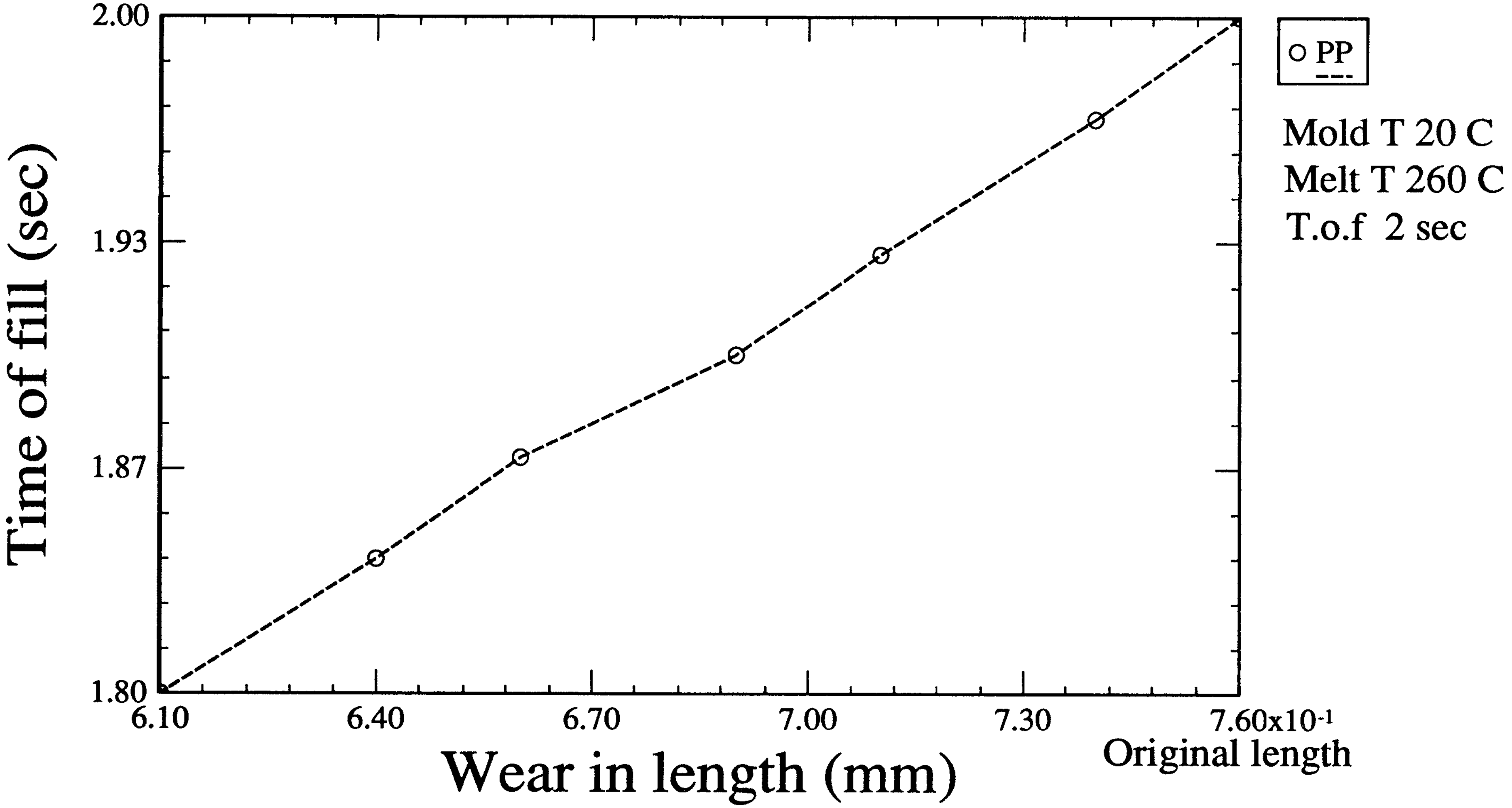


Fig. 4.26

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 13:27:10 1991 (data file was /usr/tmp/TG.AAAa15221)



Wear in length vs Time of fill

Fig. 4.27

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 13:35:53 1991 (data file was 4.27.data)

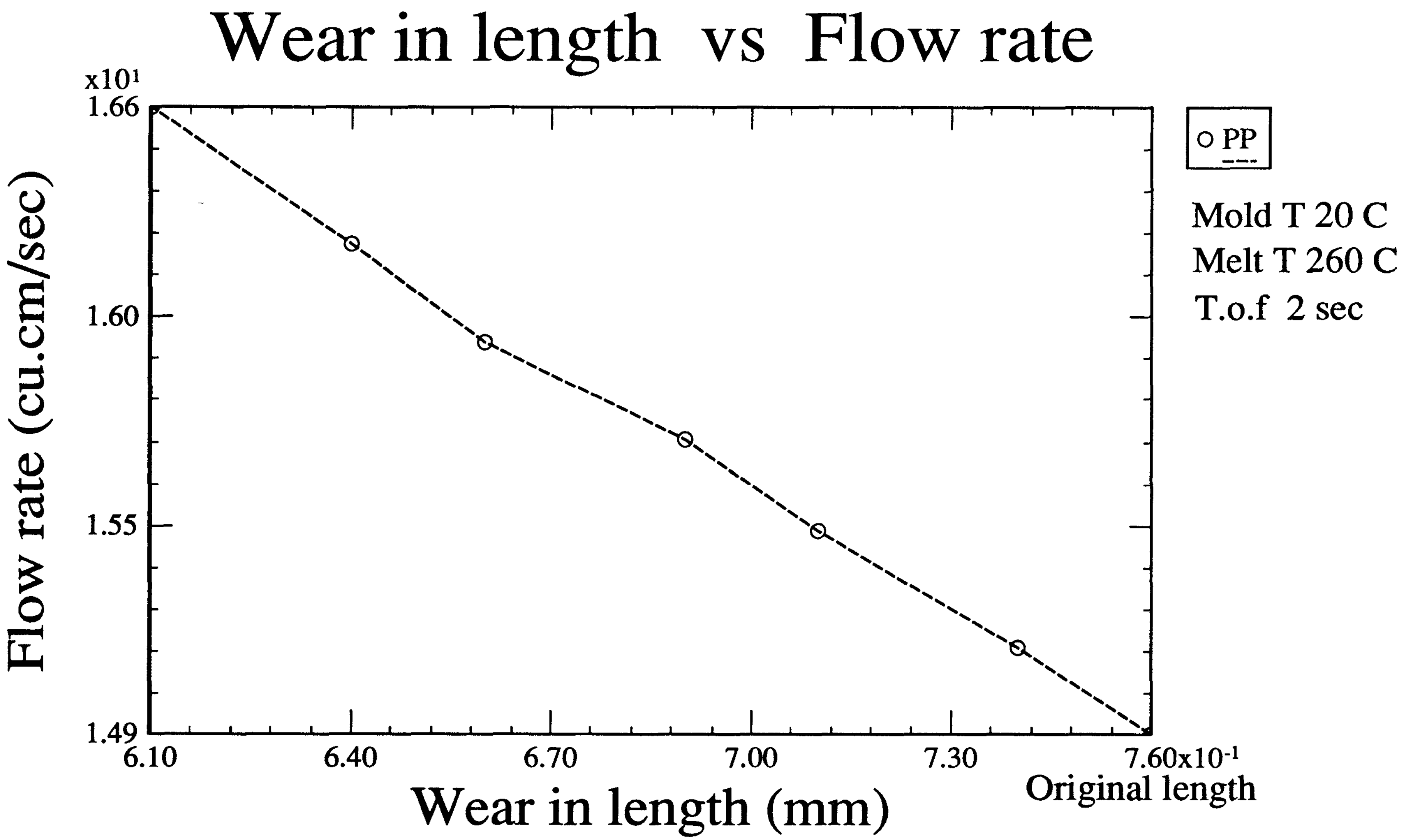


Fig. 4.28

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 13:32:30 1991 (data file was 4.28.data)

Wear in width vs Time of fill

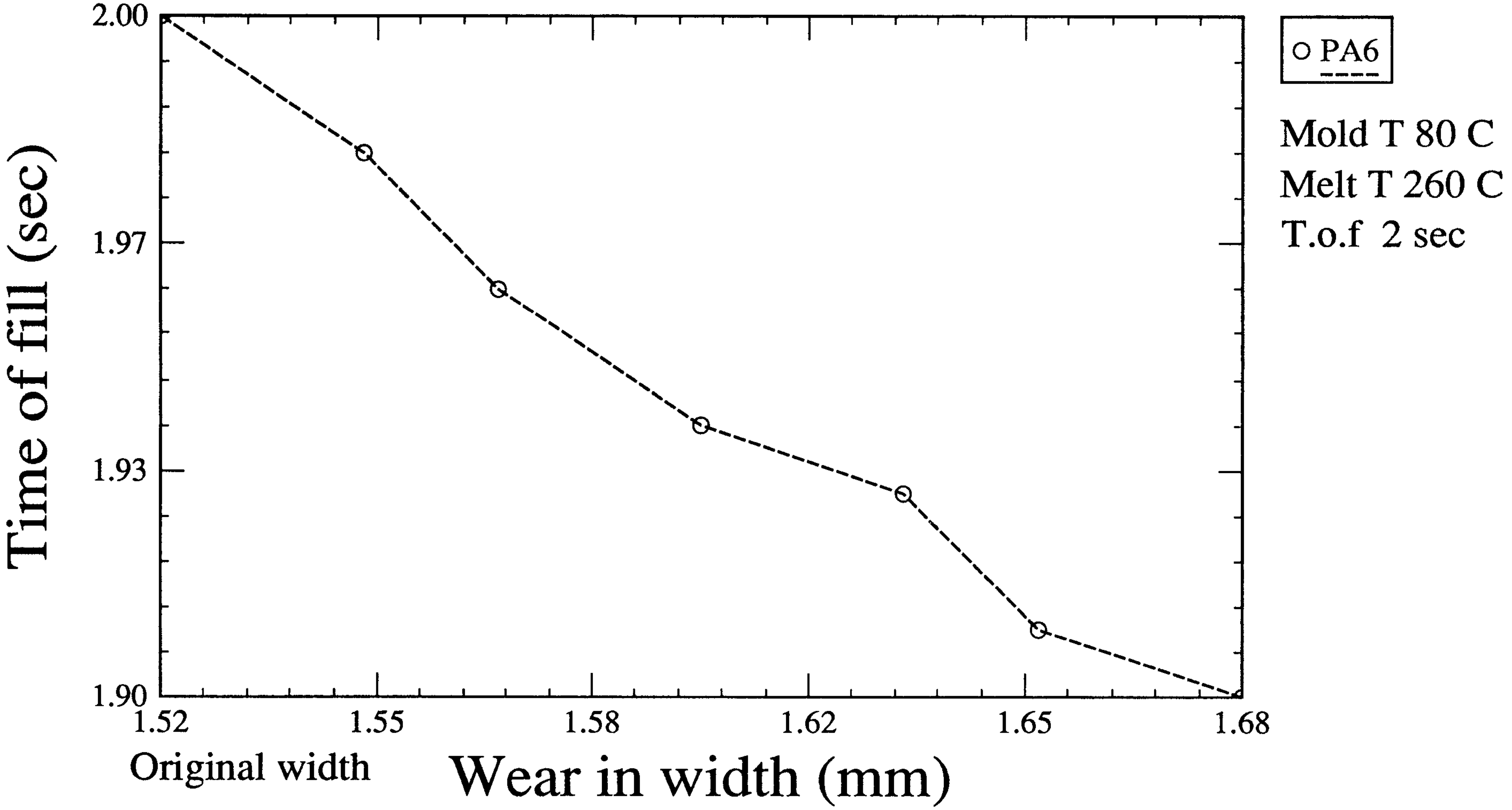


Fig. 4.29

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw55 - Sat May 4 10:59:30 1991 (data file was /usr/tmp/TG.AAAa06581)

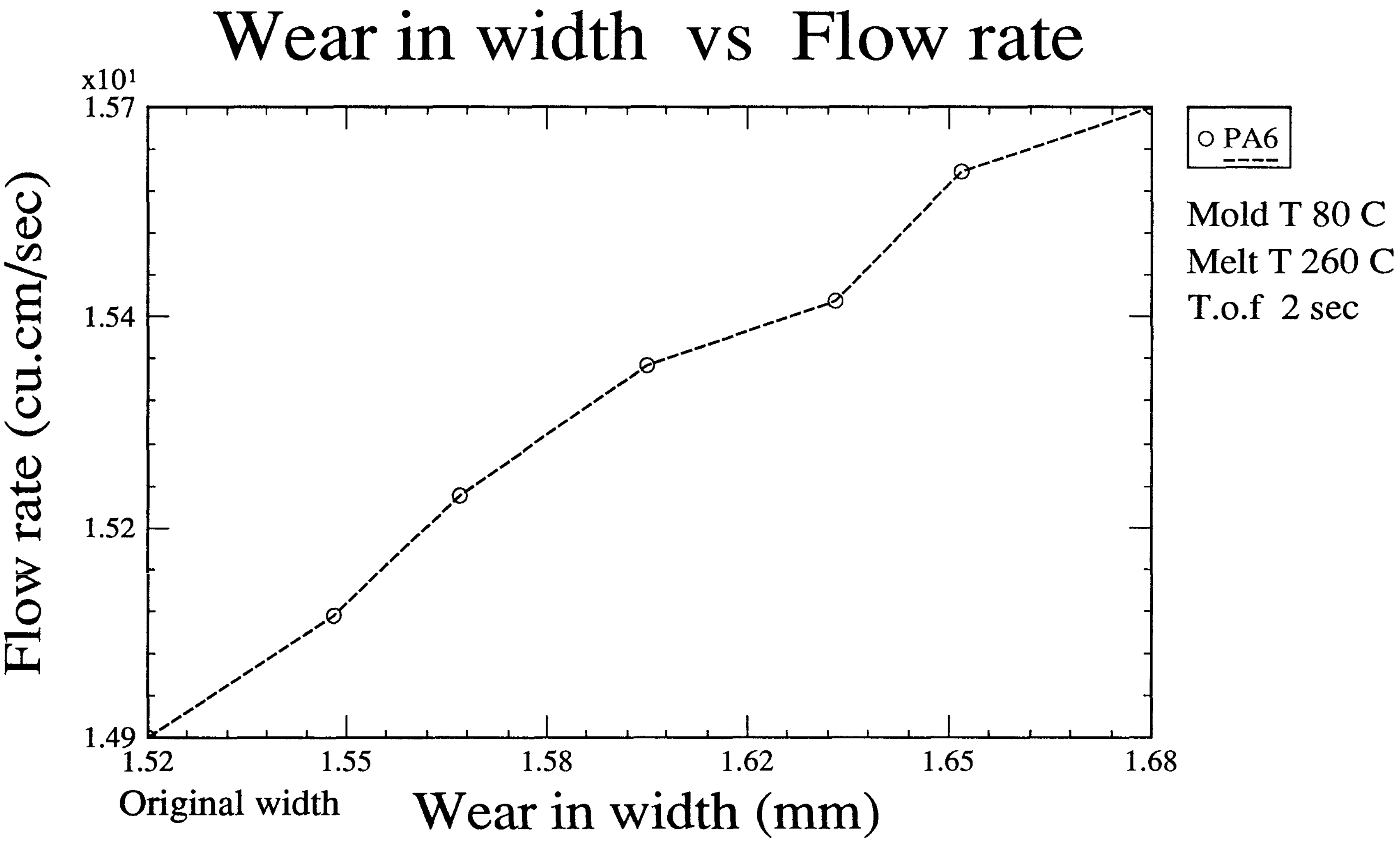

Wear in width vs Flow rate
x10¹
1.57
1.54
1.52
1.49
Flow rate (cu.cm/sec)
1.52
1.55
1.58
1.62
1.65
1.68
Original width
Wear in width (mm)
○ PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.30

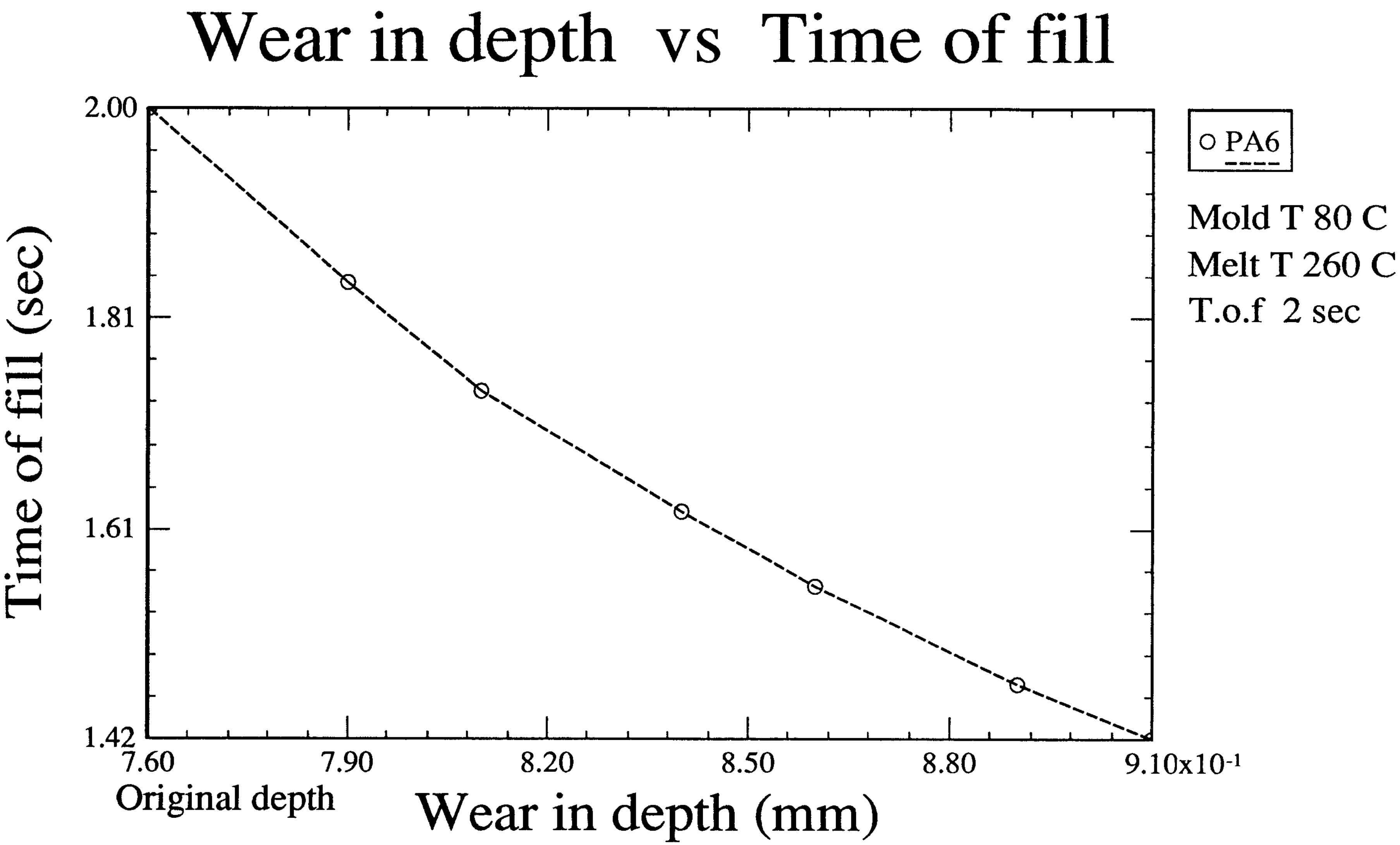


Fig. 4.31

TempleGraph 2.3. Origin: /usr/mesuna/users/rya3859@mesunw55 - Sat May 4 11:11:59 1991 (data file was /usr/tmp/TG.AAAa06581)

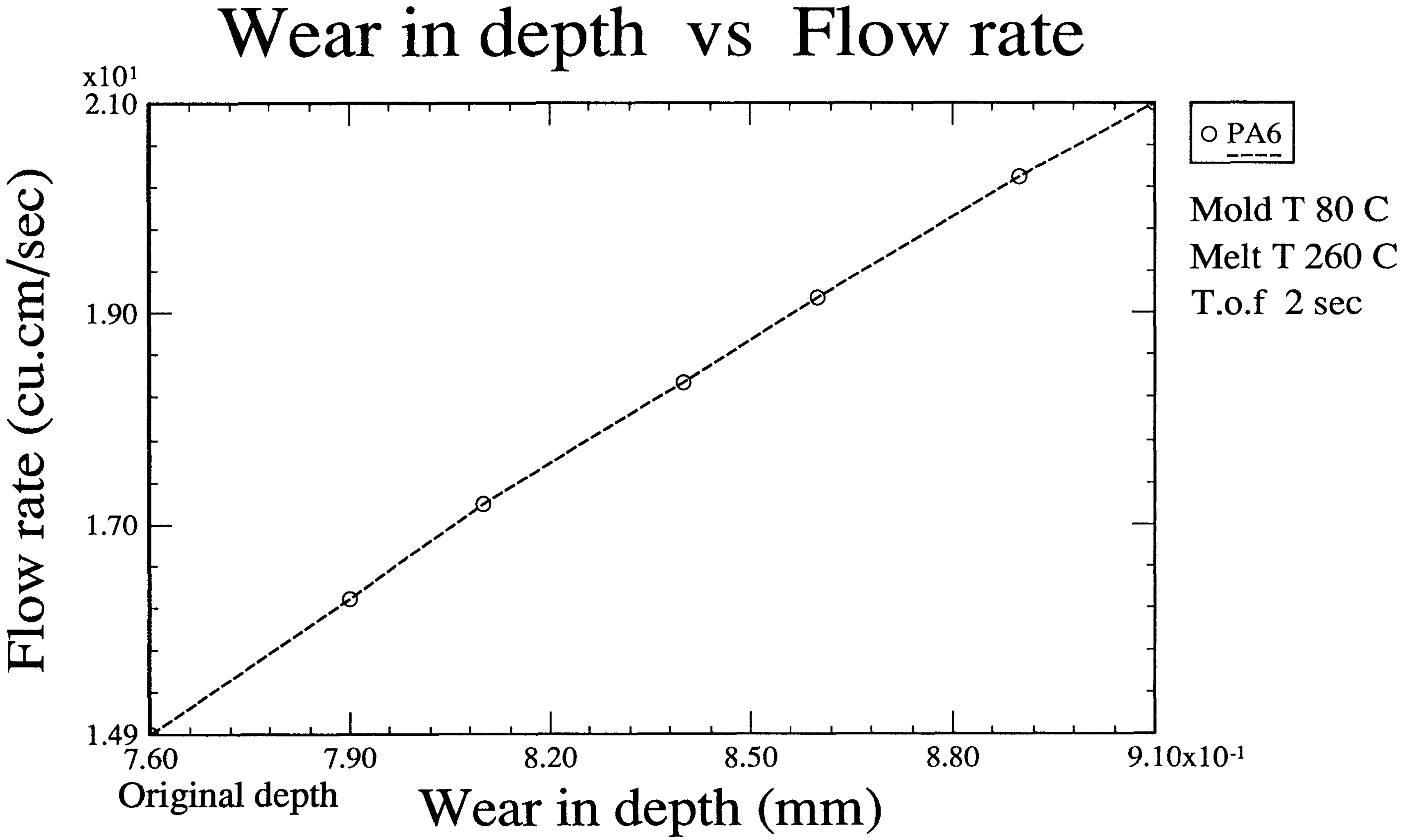


Fig. 4.32

TempleGraph 2.3 Origin: /usr/mesuna/users/rya3859@mesunw55 - Sat May 4 11:07:59 1991 (data file was /usr/tmp/TG AAAa06581)

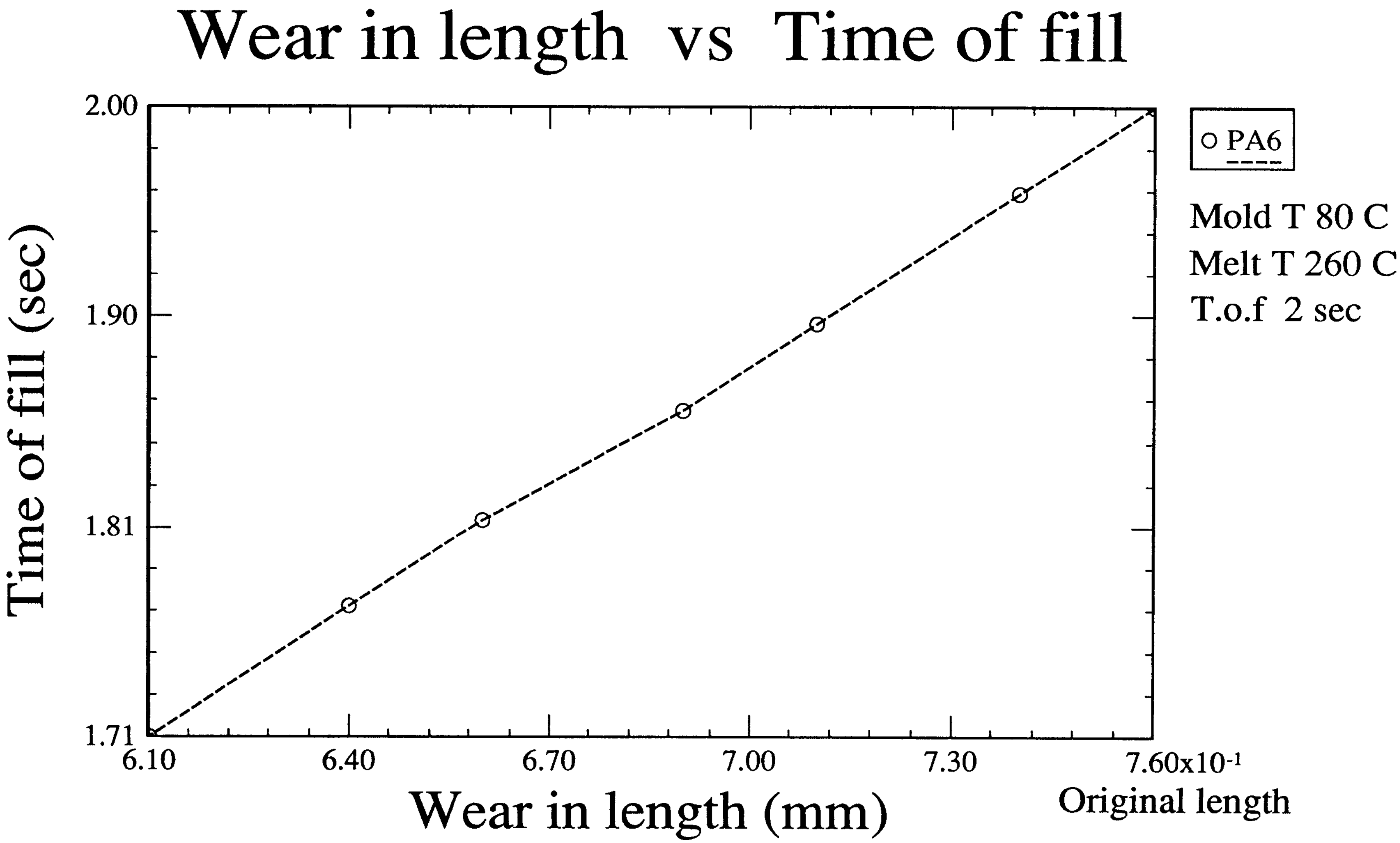


Fig. 4.33

TempleGraph 2.3 Origin: /usr/mesuna/users/rya3859@mesunw55 - Sat May 4 11:15:46 1991 (data file was /usr/tmp/TG AAAa06581)

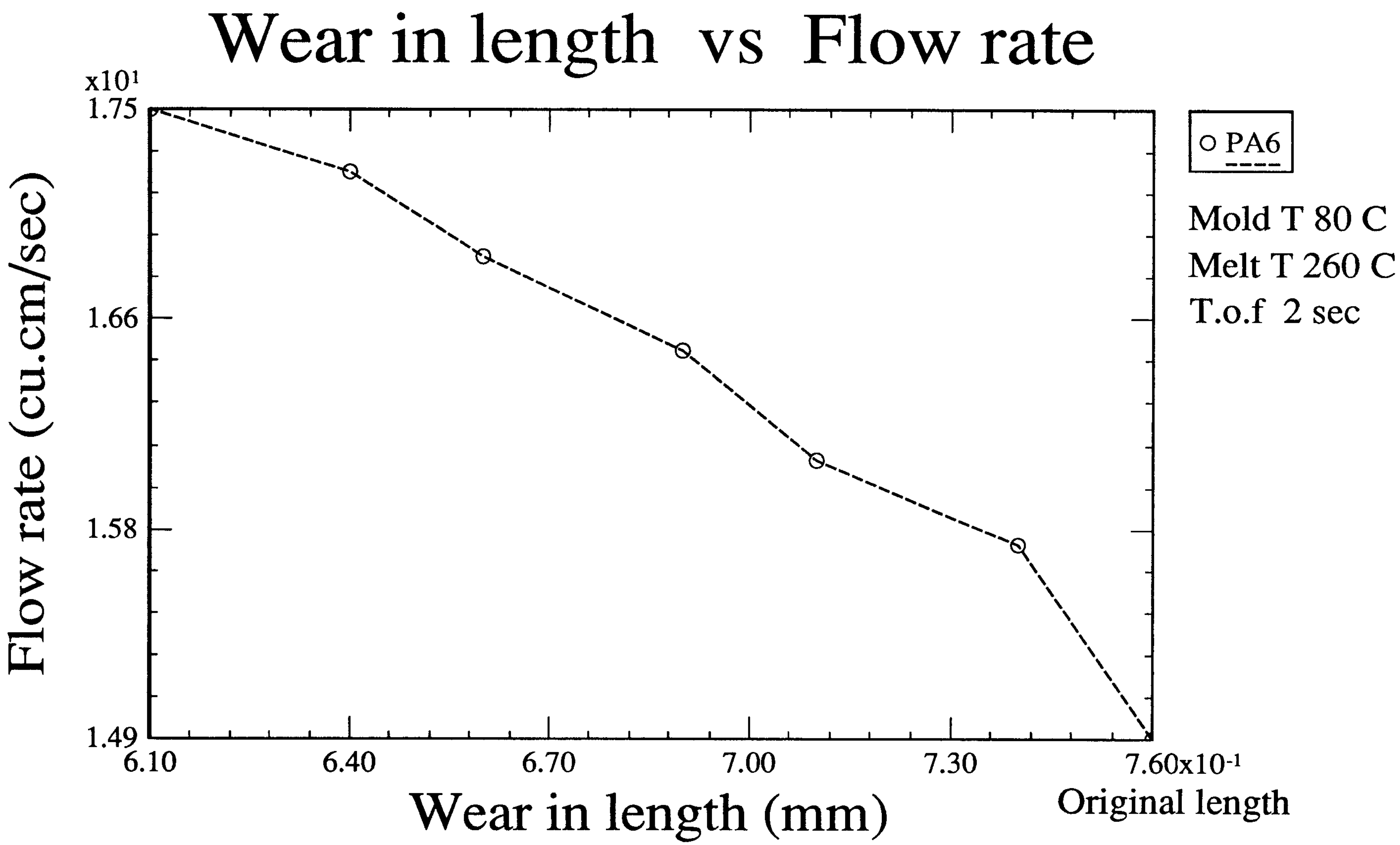

Wear in length vs Flow rate
x10¹
1.75
1.66
1.58
1.49
Flow rate (cu.cm/sec)
6.10
6.40
6.70
7.00
7.30
7.60x10⁻¹
Original length
Wear in length (mm)
PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.34

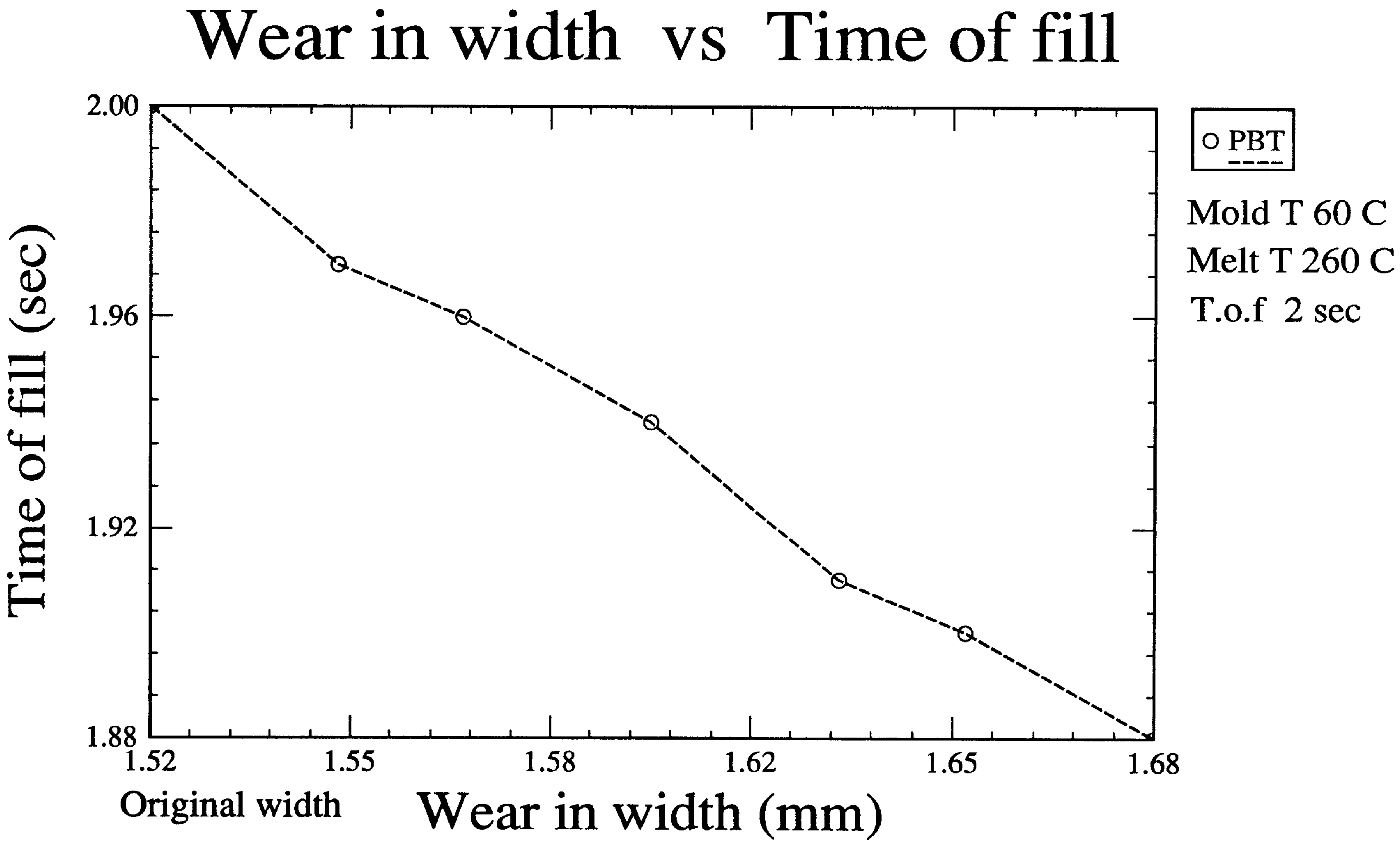


Fig. 4.35

TempleGraph 2.3 Origin: /usr/mesuna/users/rya3859@mesunw57 - Fri May 3 10:18:59 1991 (data file was /usr/tmp/TG.AAAa15007)

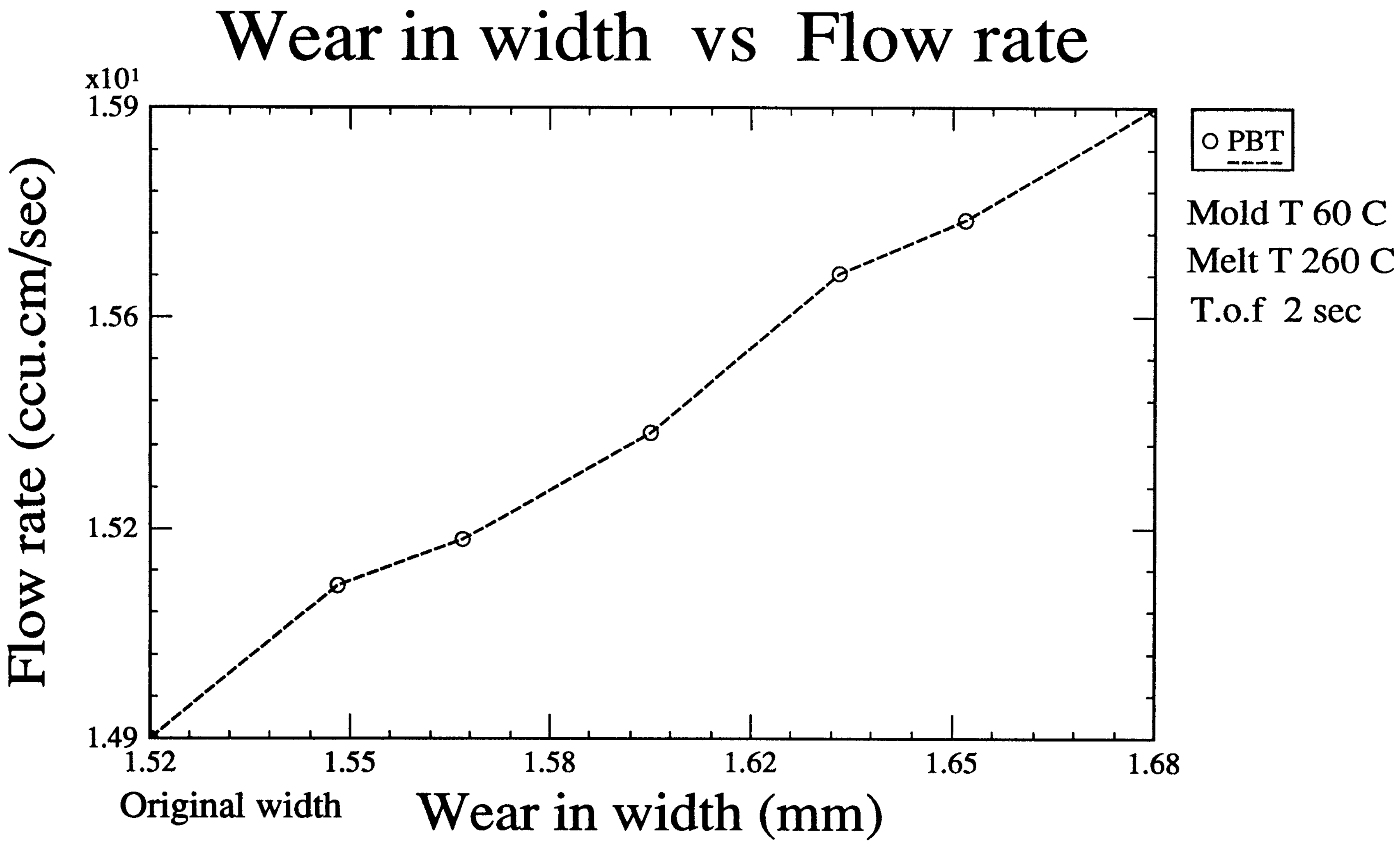


Fig. 4.36

TempleGraph 2.3 Origin: /usr/mesuna/users/rya3859@mesunw57 - Fri May 3 10:28:52 1991 (data file was /usr/tmp/TG.AAAa15007)

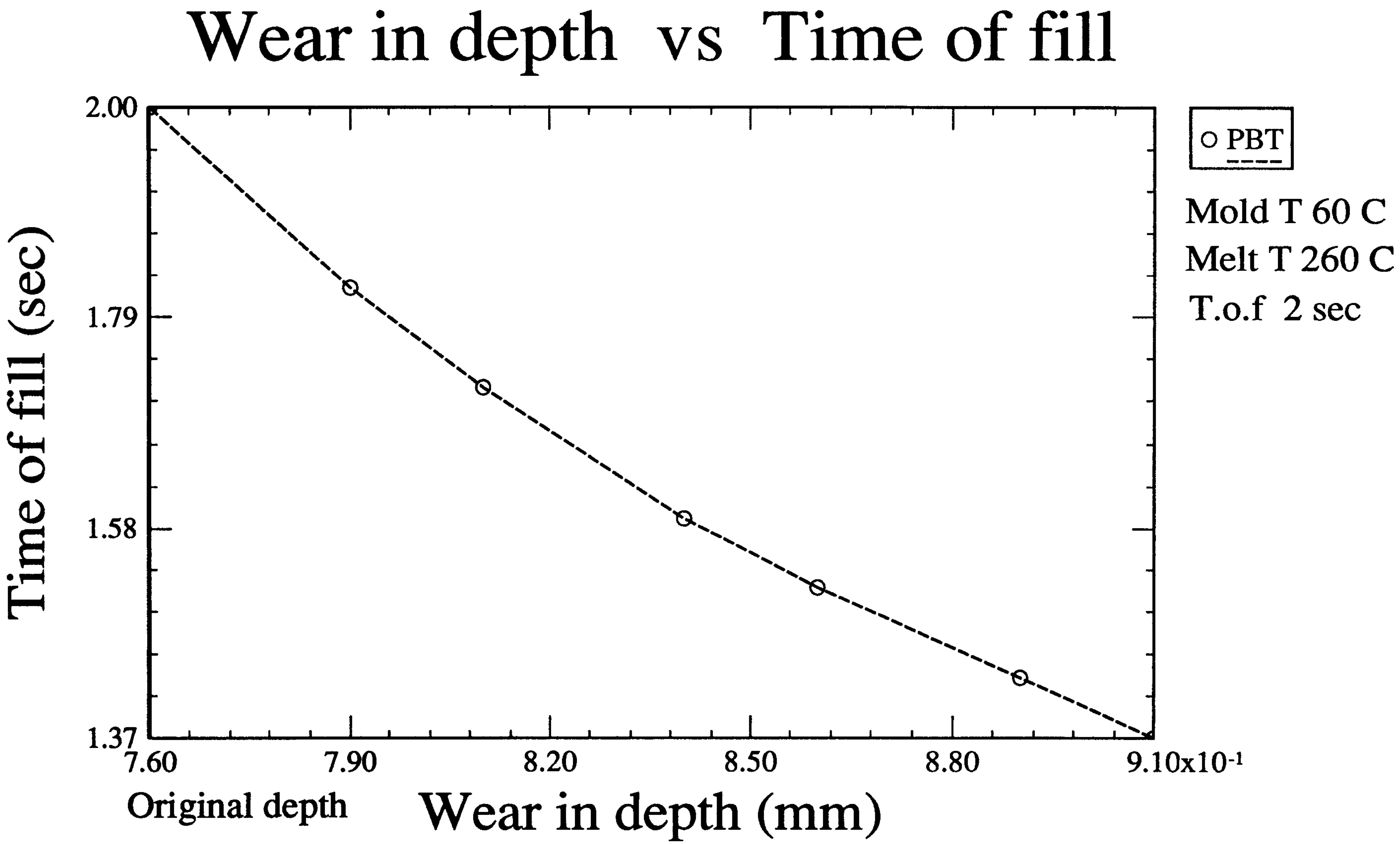


Fig. 4.37

TempleGraph 2.3, Origin: /usr/mesuna/users/rya3859@mesunw57 - Fri May 3 11:16:40 1991 (data file was /usr/tmp/TG.AAAa15007)

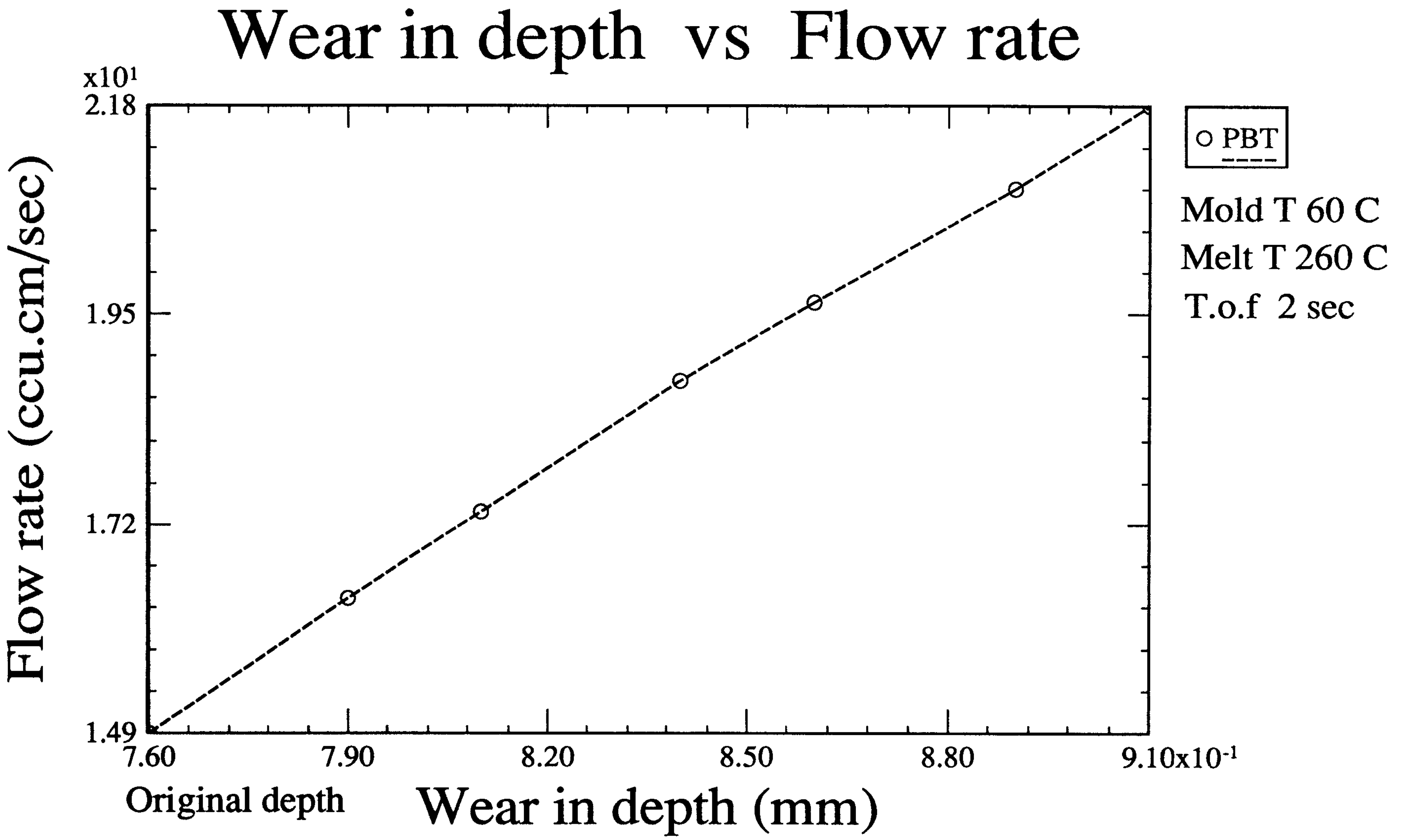

Wear in depth vs Flow rate
x10¹
2.18
1.95
1.72
1.49
Flow rate (ccu.cm/sec)
7.60
7.90
8.20
8.50
8.80
9.10x10⁻¹
Original depth
Wear in depth (mm)
○ PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.38

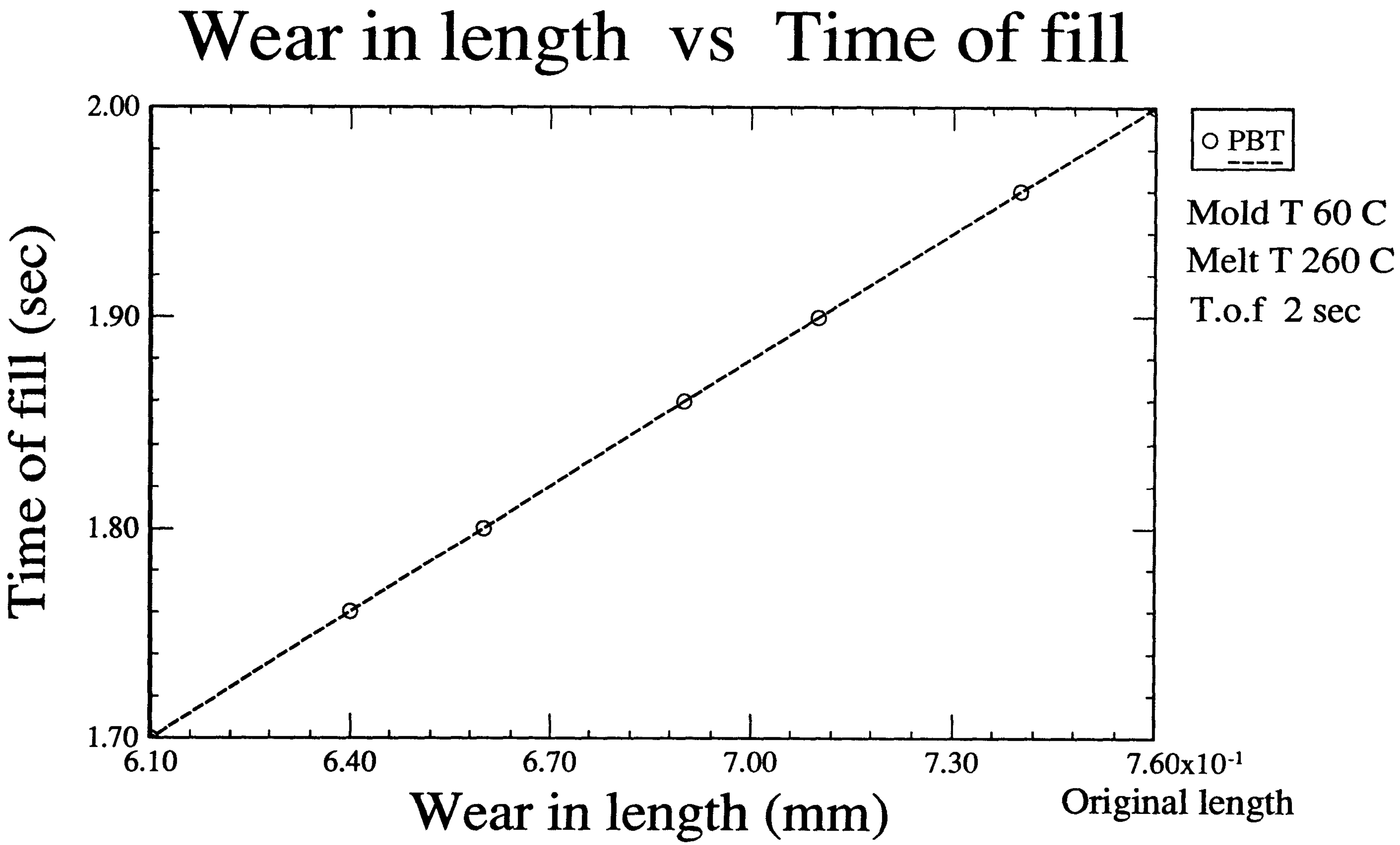


Fig. 4.39

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 11:28:02 1991 (data file was /usr/tmp/TG.AAAa15007)

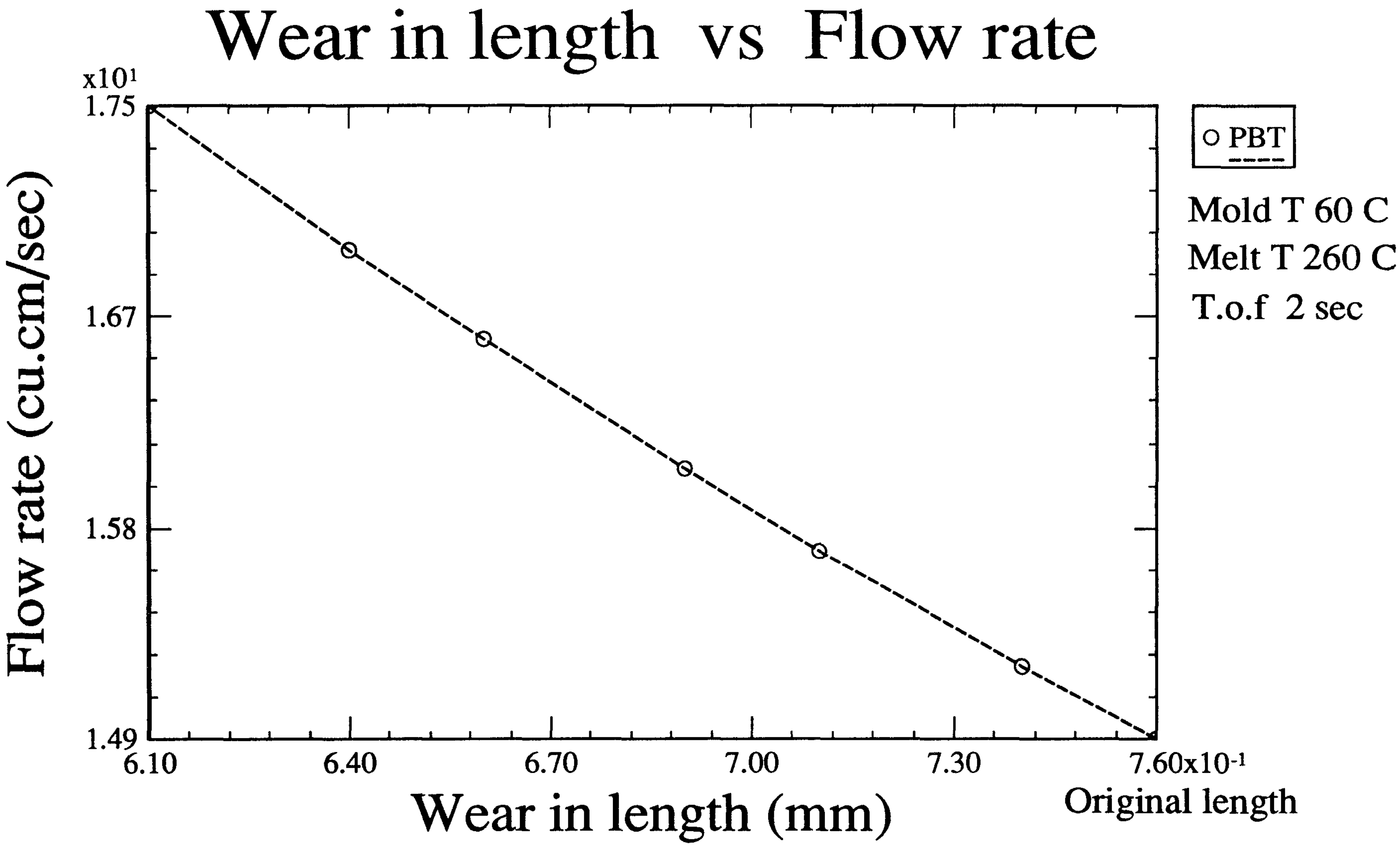


Fig. 4.40

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 11:31:48 1991 (data file was /usr/tmp/TG.AAAa15007)

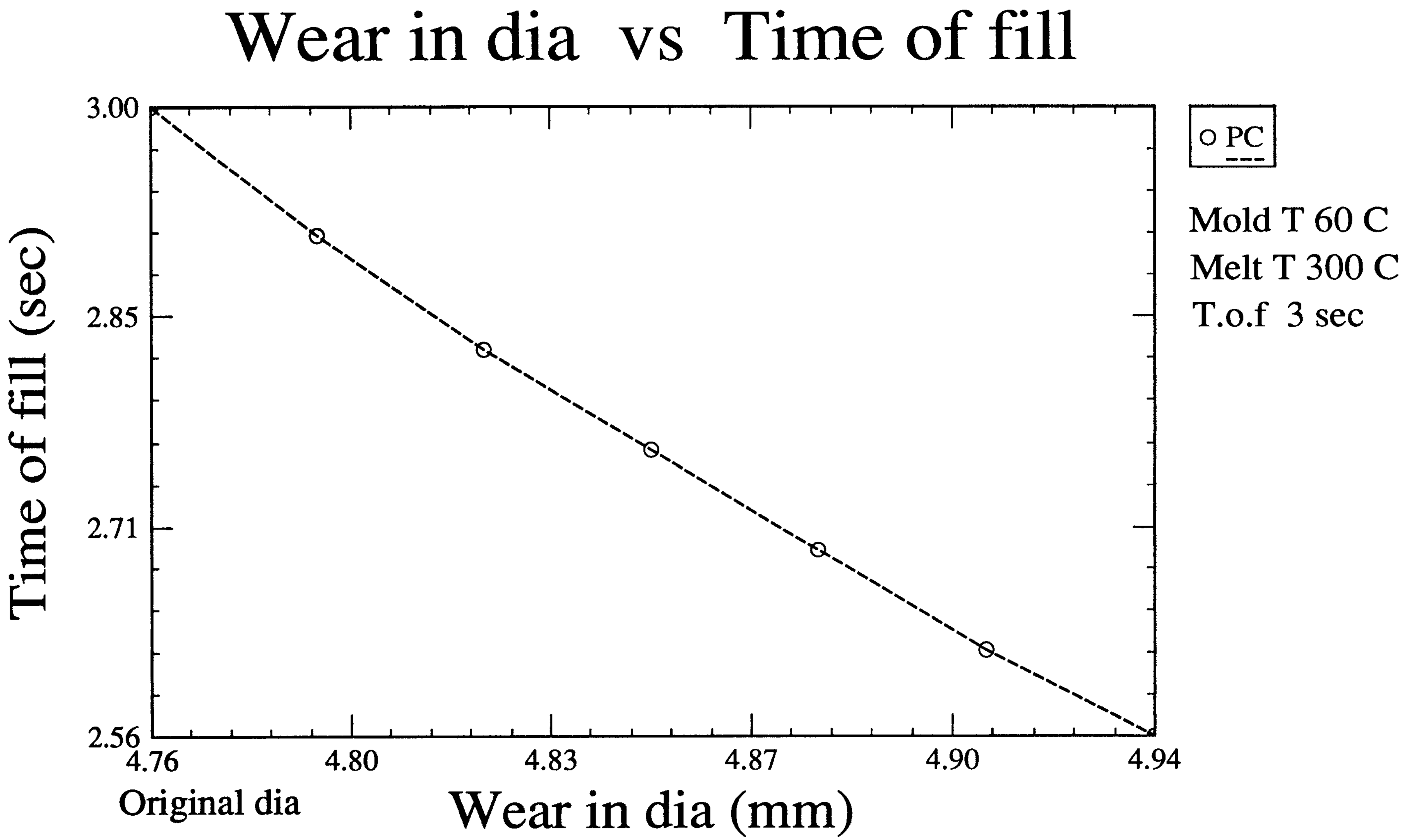


Fig. 4.41

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw55 - Sat May 4 11:56:01 1991 (data file was /usr/tmp/TG.AAAa06581)

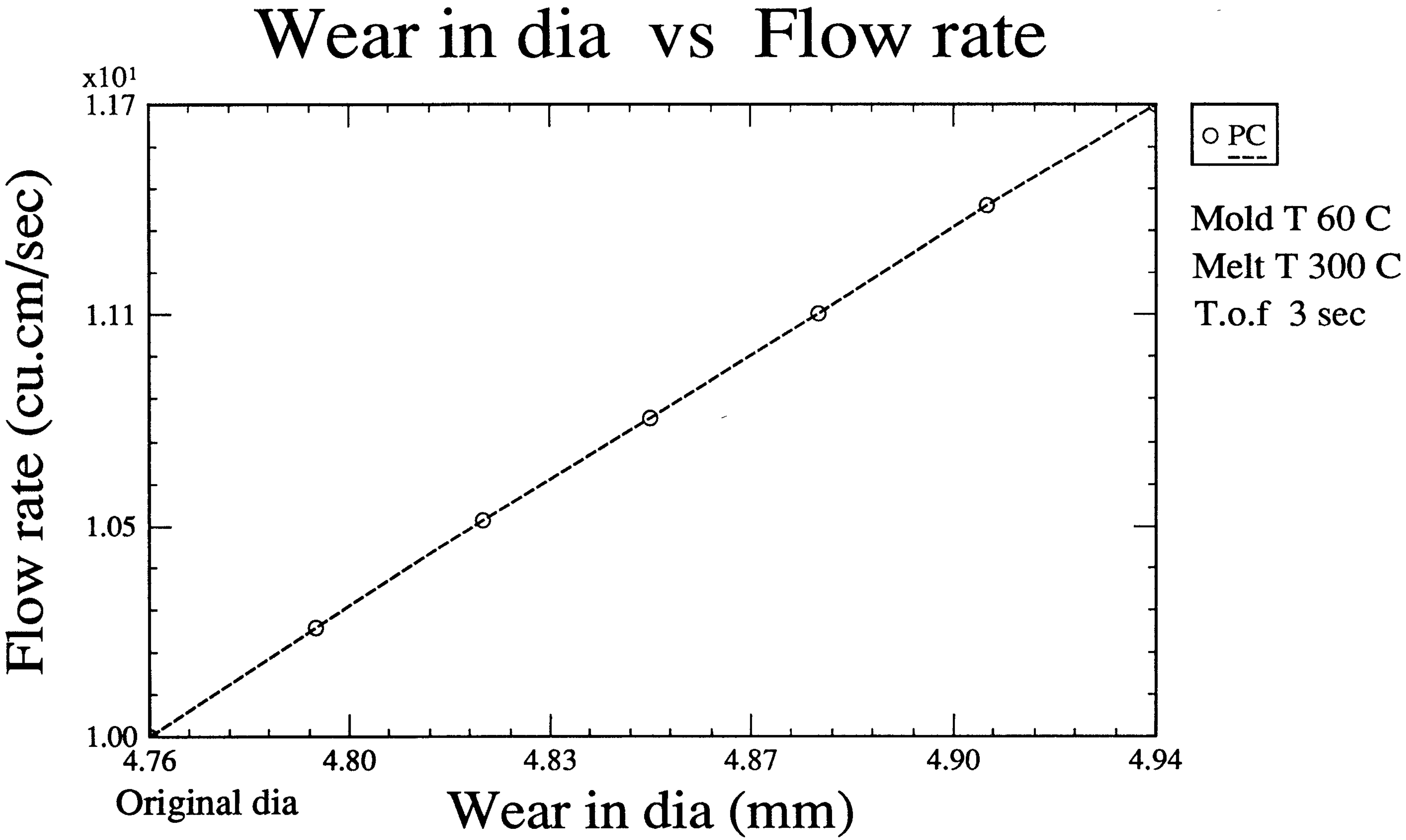


Fig. 4.42

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw55 - Sat May 4 11:52:00 1991 (data file was /usr/tmp/TG.AAAa06581)

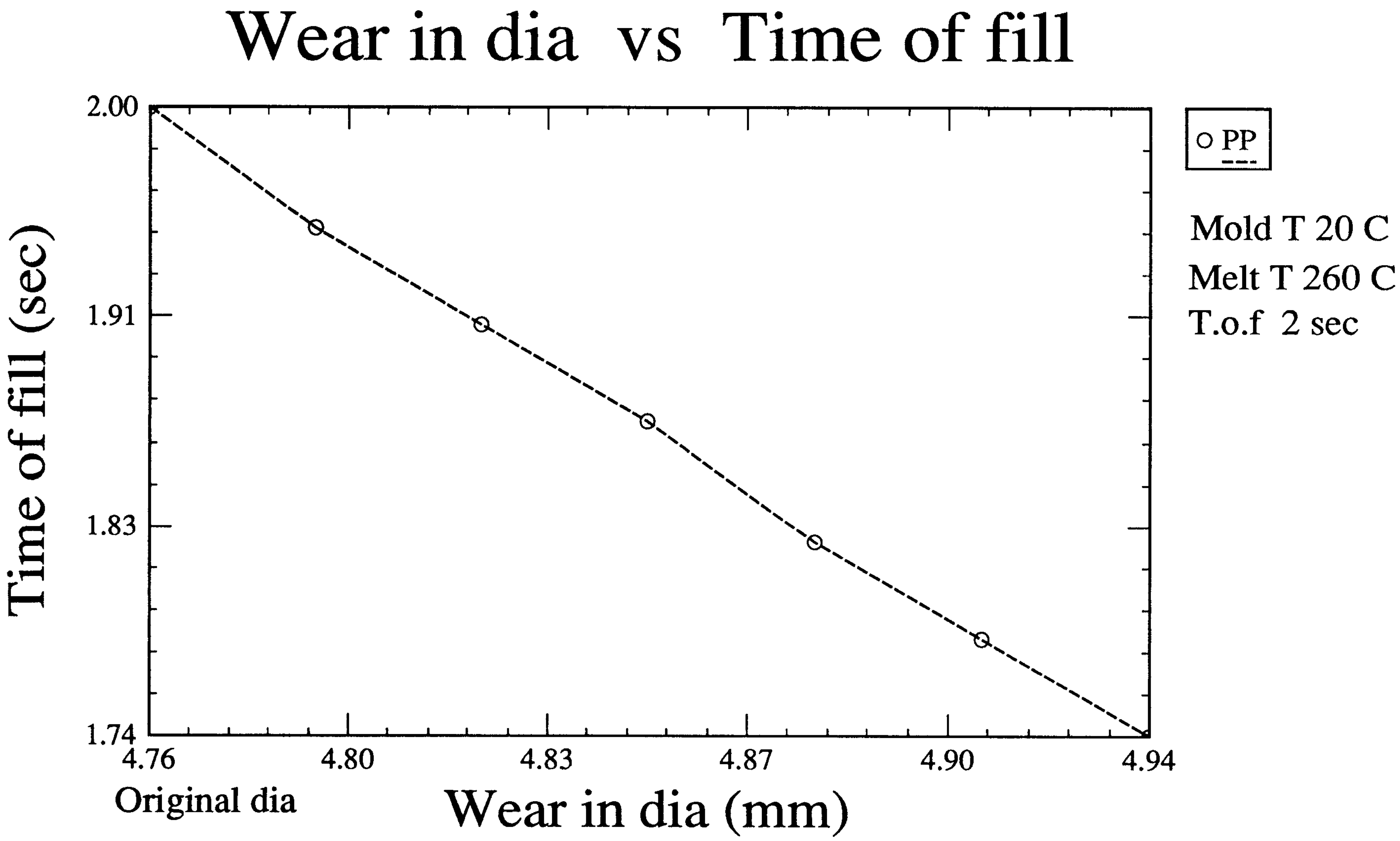

Wear in dia vs Time of fill
Time of fill (sec)
2.00
1.91
1.83
1.74
4.76
4.80
4.83
4.87
4.90
4.94
Original dia
Wear in dia (mm)
○ PP
Mold T 20 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.43

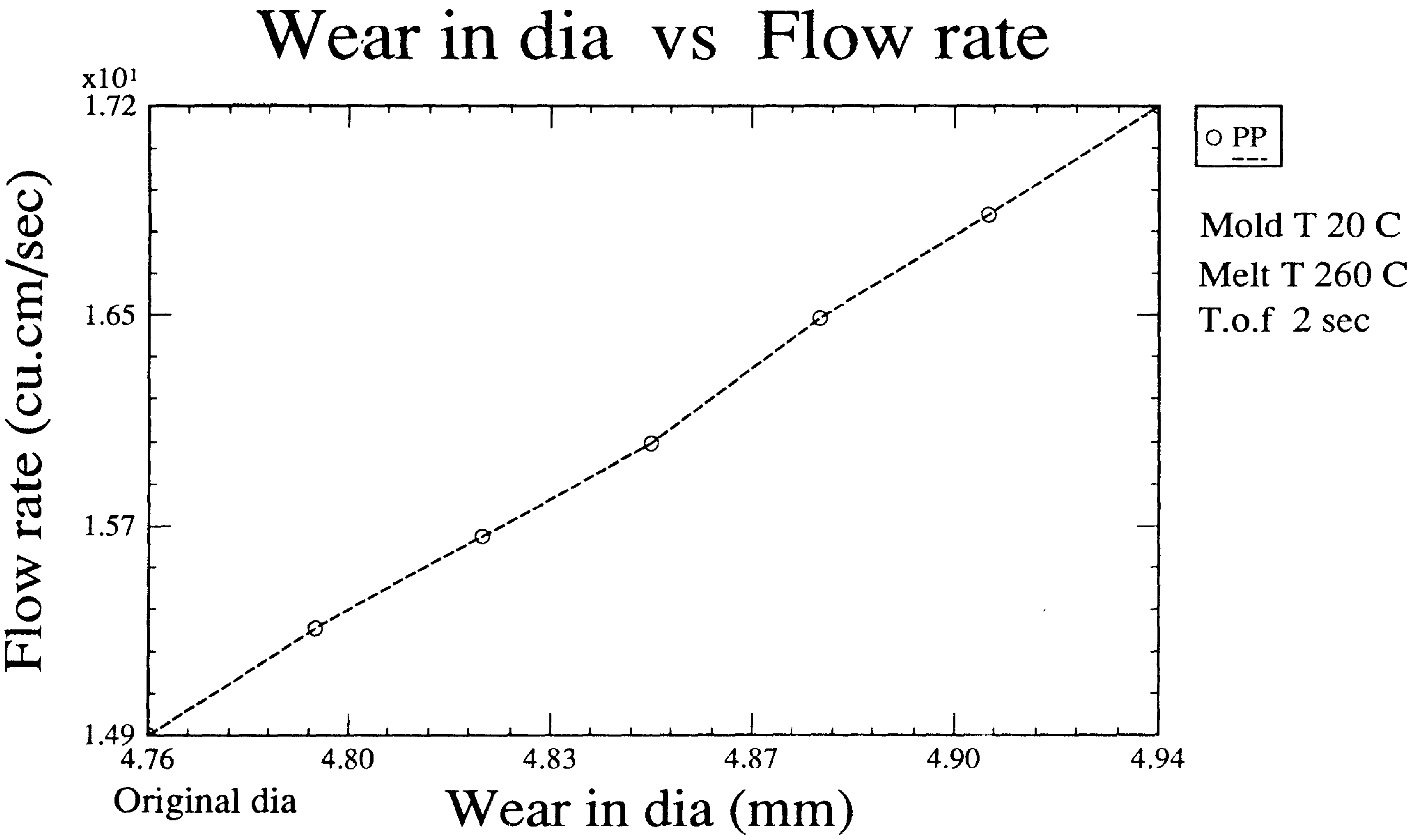


Fig. 4.44

TempleGraph 2.3, Origin /usr/mesuna/users/rva3859@mesunw55 - Sat May 4 12:06:10 1991 (data file was /usr/tmp/TG AAAa06581)

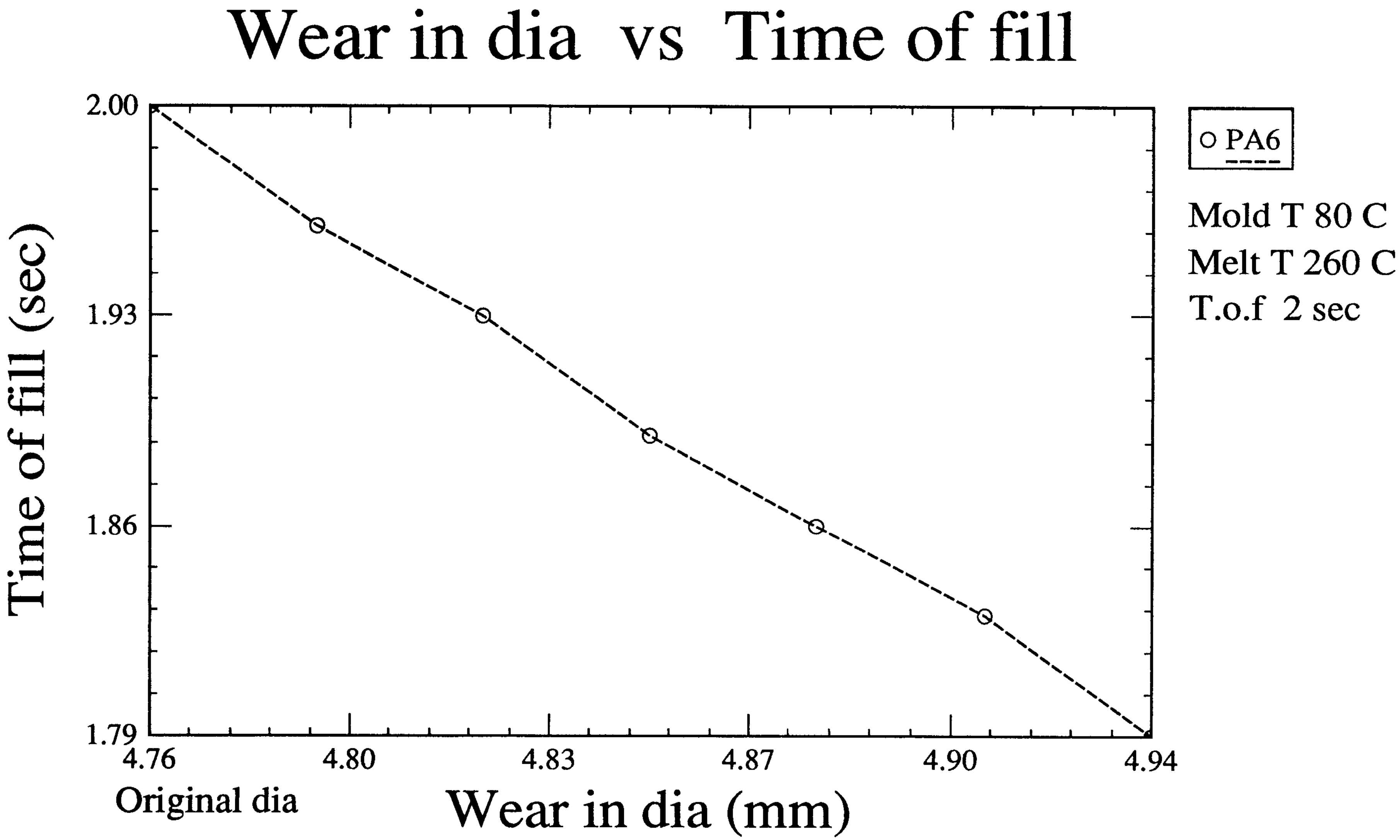


Fig. 4.45

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw55 - Sat May 4 11:35:53 1991 (data file was /usr/tmp/TG.AAAa06581)

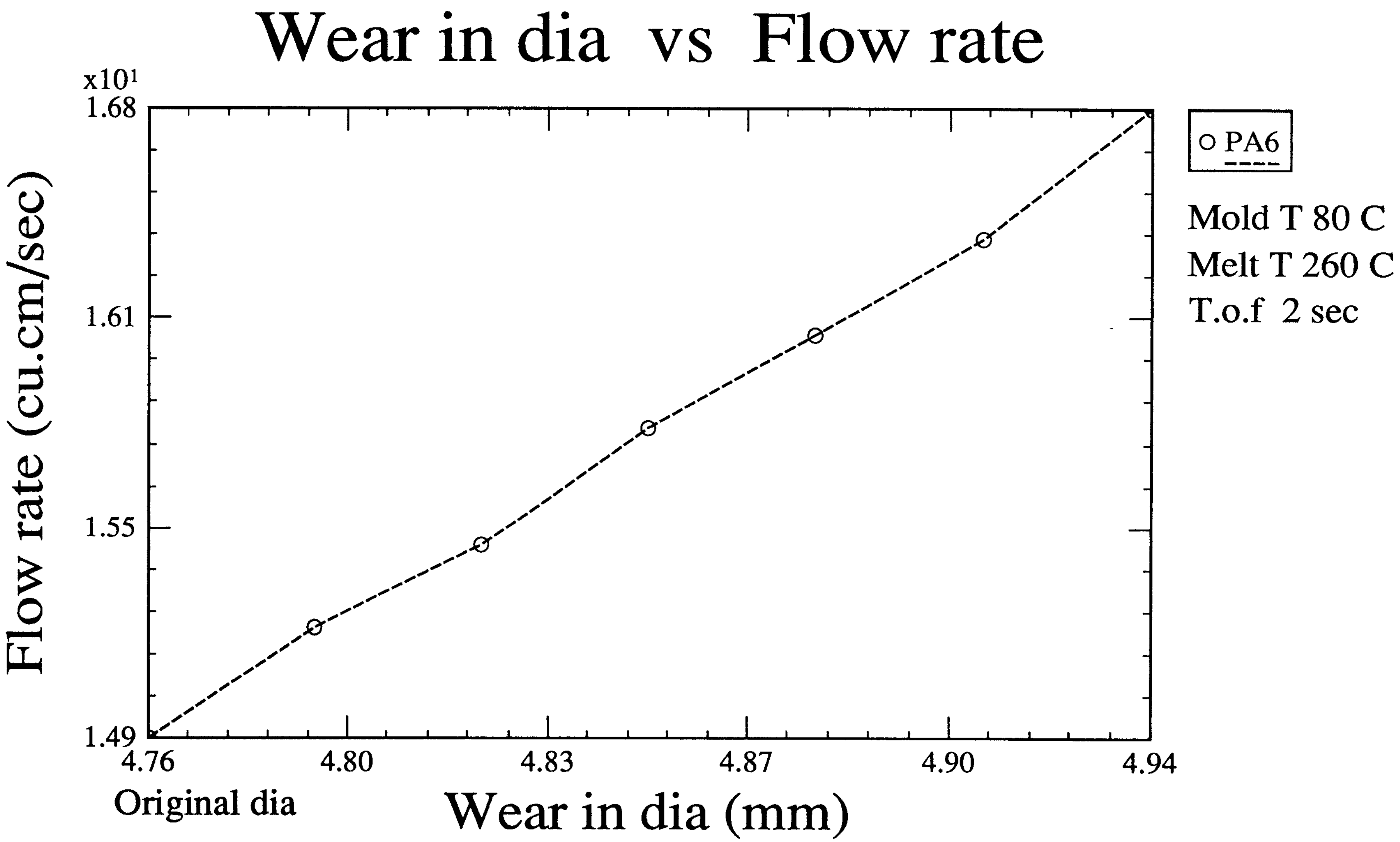

Wear in dia vs Flow rate
x10¹
1.68
1.61
1.55
1.49
Flow rate (cu.cm/sec)
4.76
4.80
4.83
4.87
4.90
4.94
Original dia
Wear in dia (mm)
○ PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.46

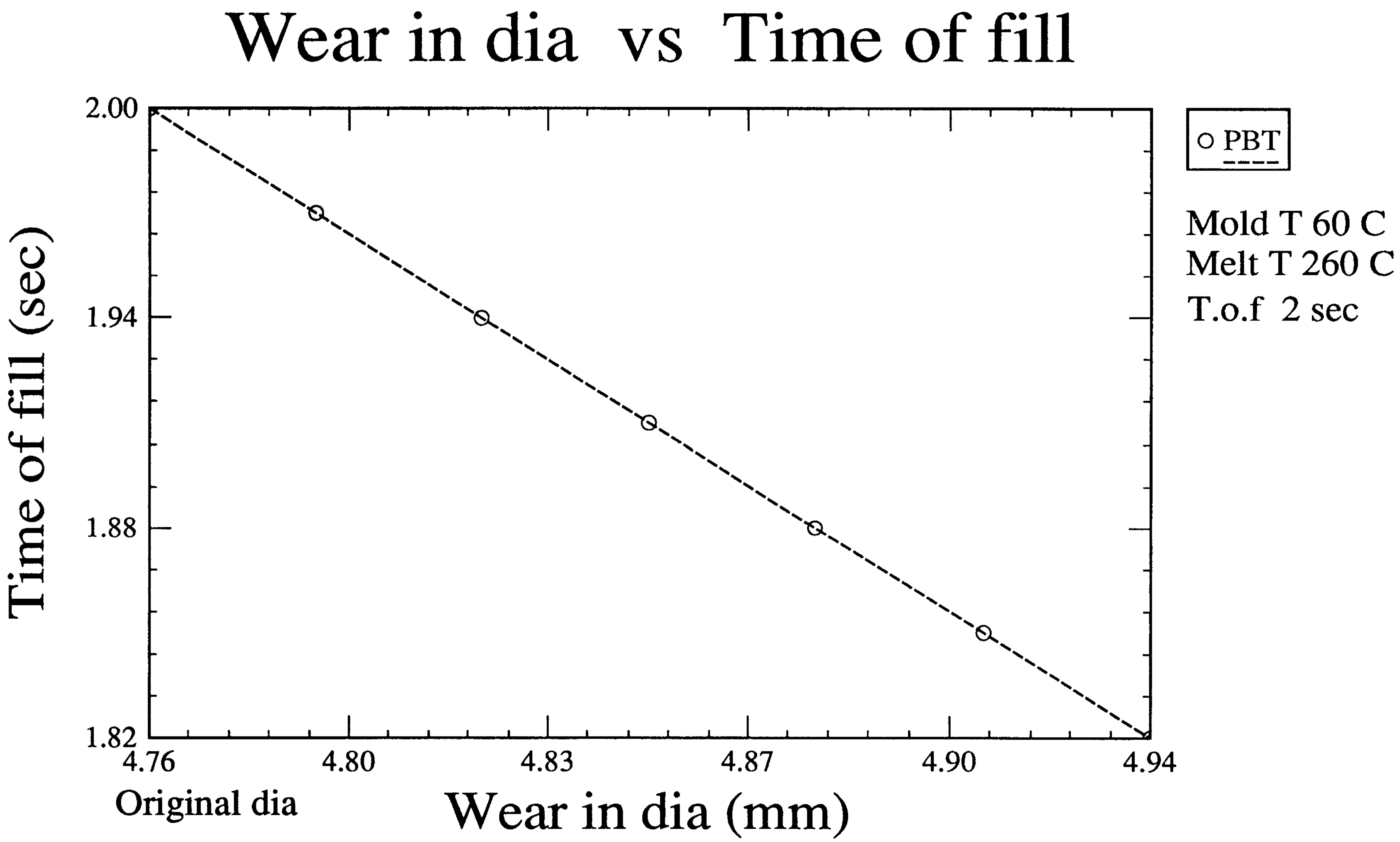

Wear in dia vs Time of fill
Time of fill (sec)
2.00
1.94
1.88
1.82
4.76
4.80
4.83
4.87
4.90
4.94
Original dia
Wear in dia (mm)
○ PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.47

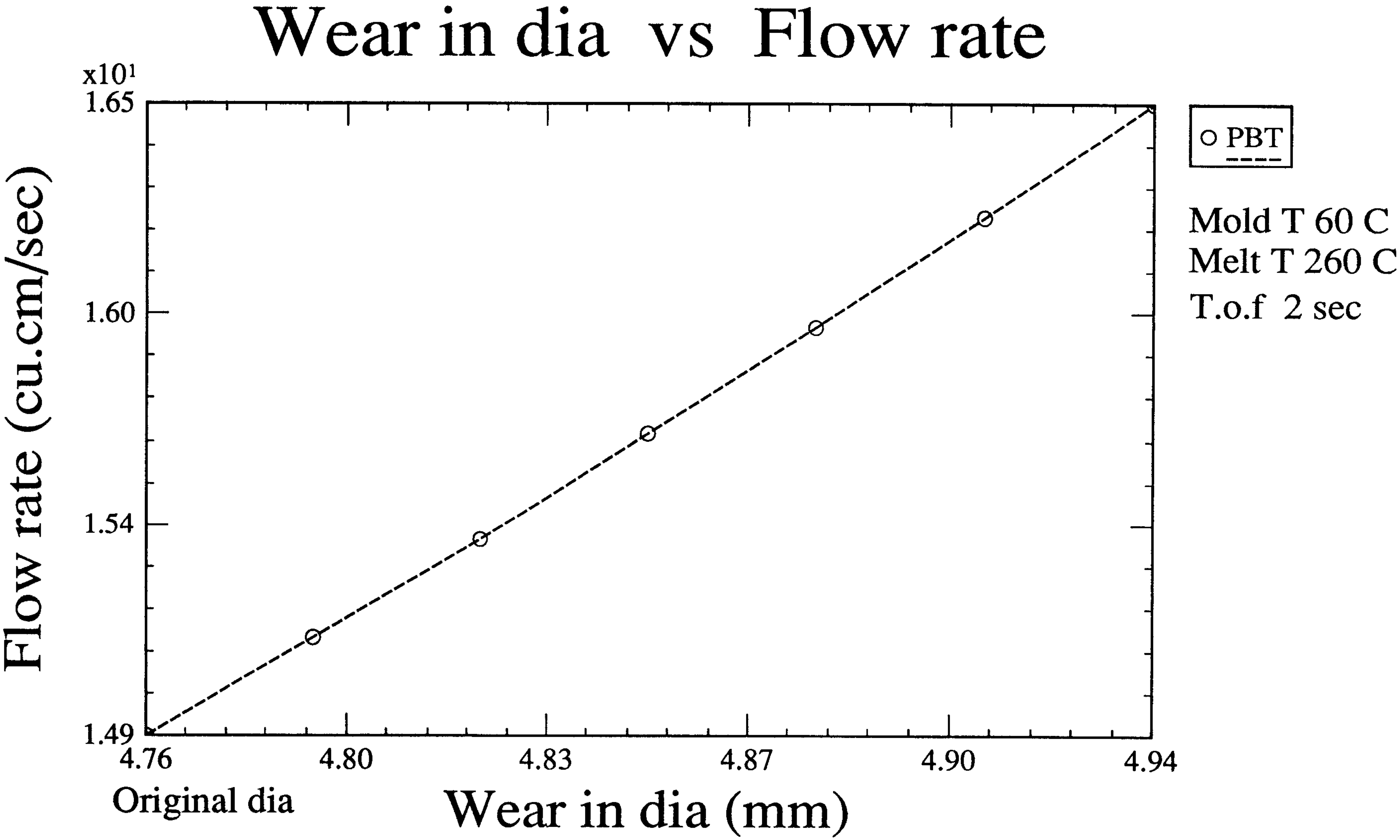

Wear in dia vs Flow rate
x10¹
1.65
1.60
1.54
1.49
Flow rate (cu.cm/sec)
4.76
4.80
4.83
4.87
4.90
4.94
Original dia
Wear in dia (mm)
○ PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.48

Wear in width vs Time of fill

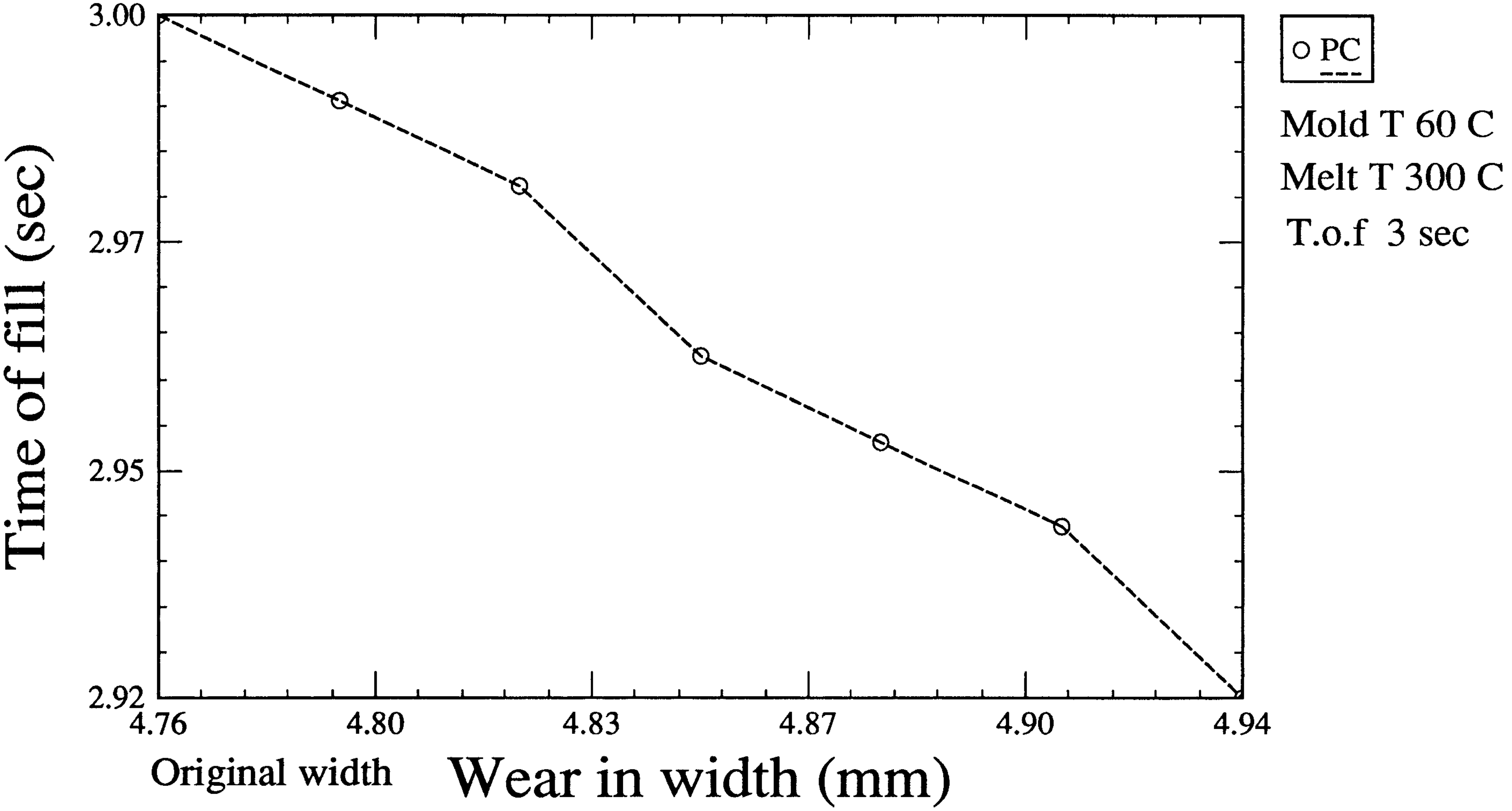


Fig. 4.49

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:04:06 1991 (data file was /usr/tmp/TG.AAAa04328)

Wear in width vs Flow rate

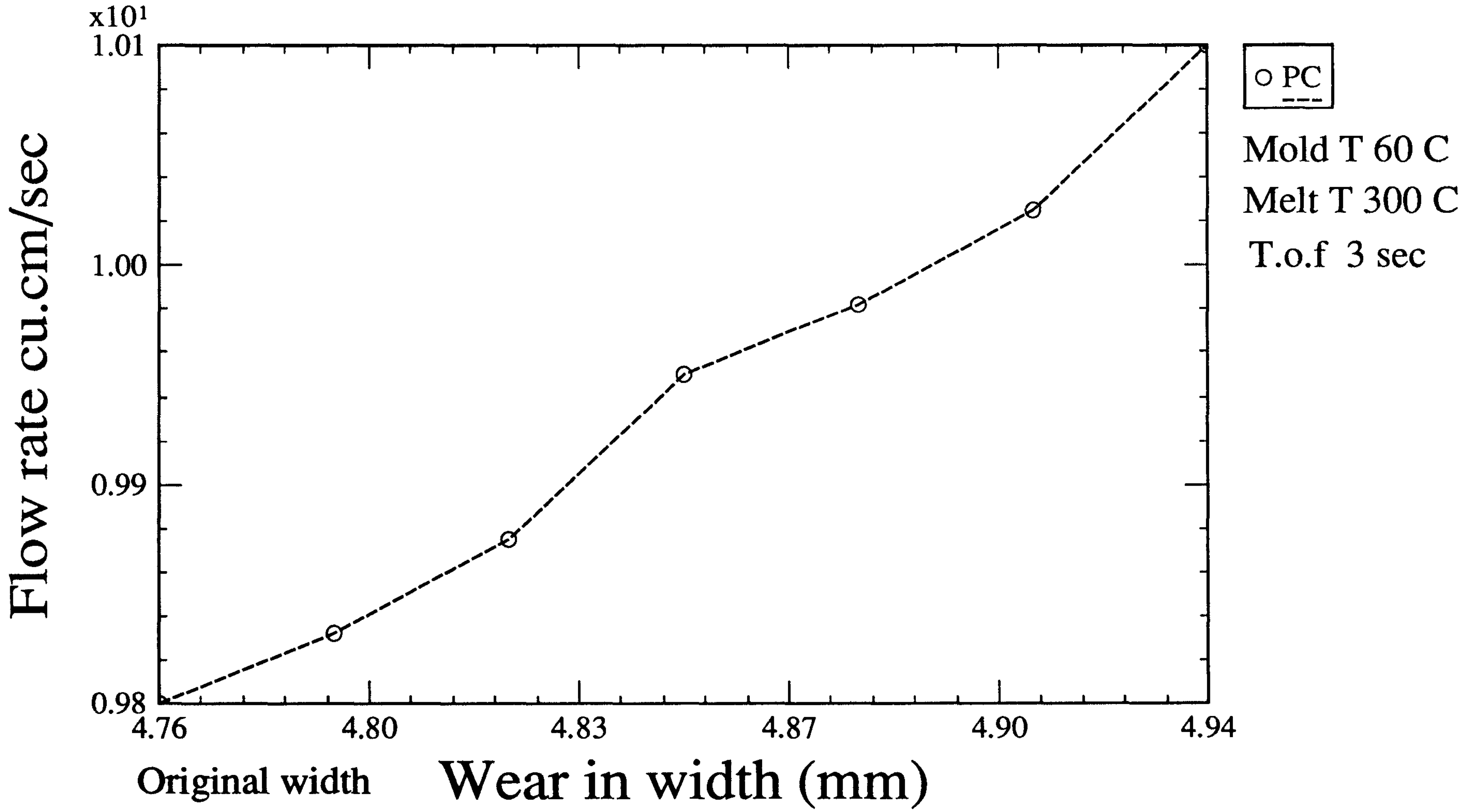


Fig. 4.50

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:29:17 1991 (data file was /usr/tmp/TG.AAAa04328)

Wear in depth Vs Time of fill

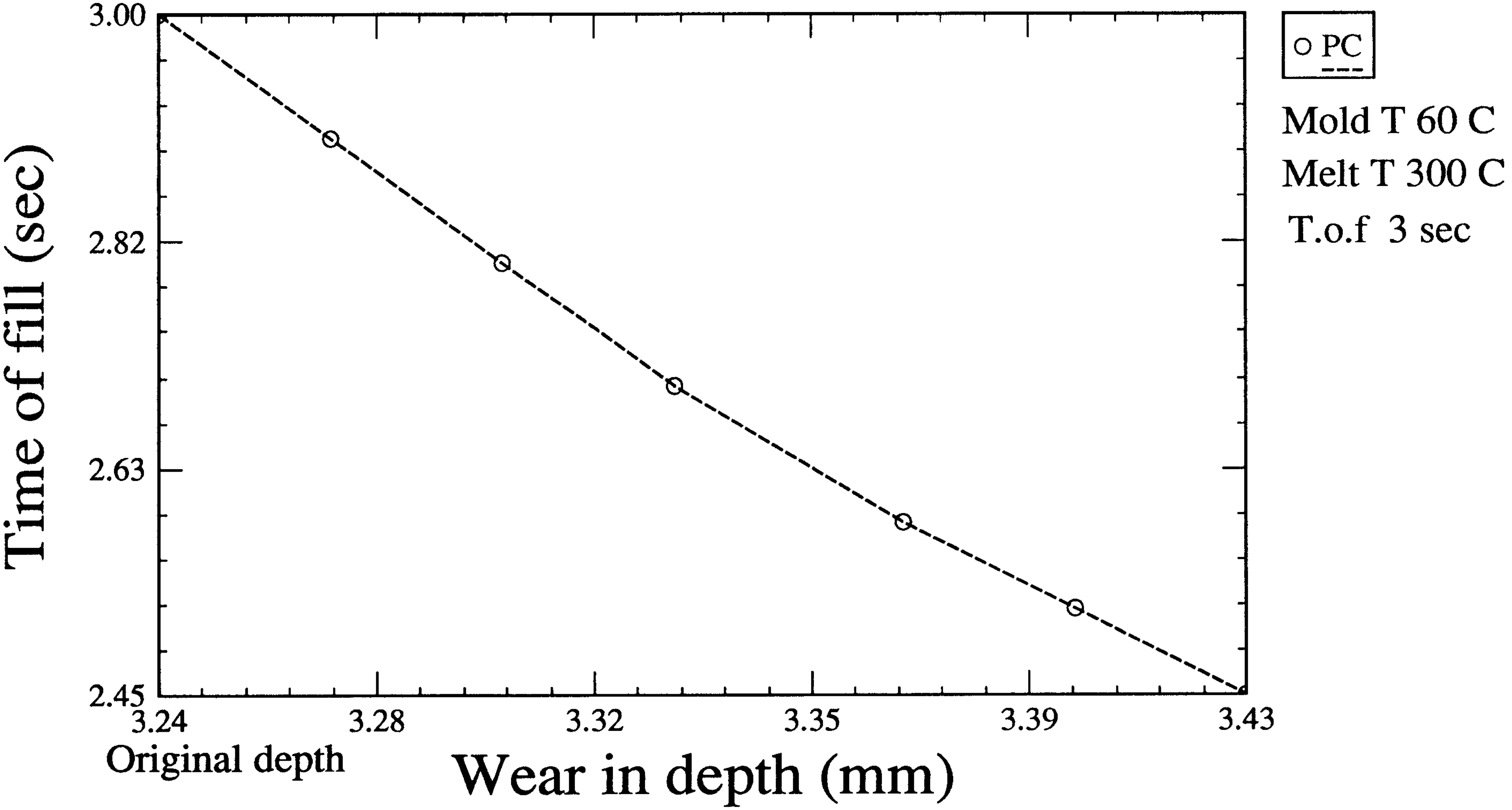


Fig. 4.51

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:14:34 1991 (data file was /usr/tmp/TG.AAAa04328)

Wear in depth vs Flow rate

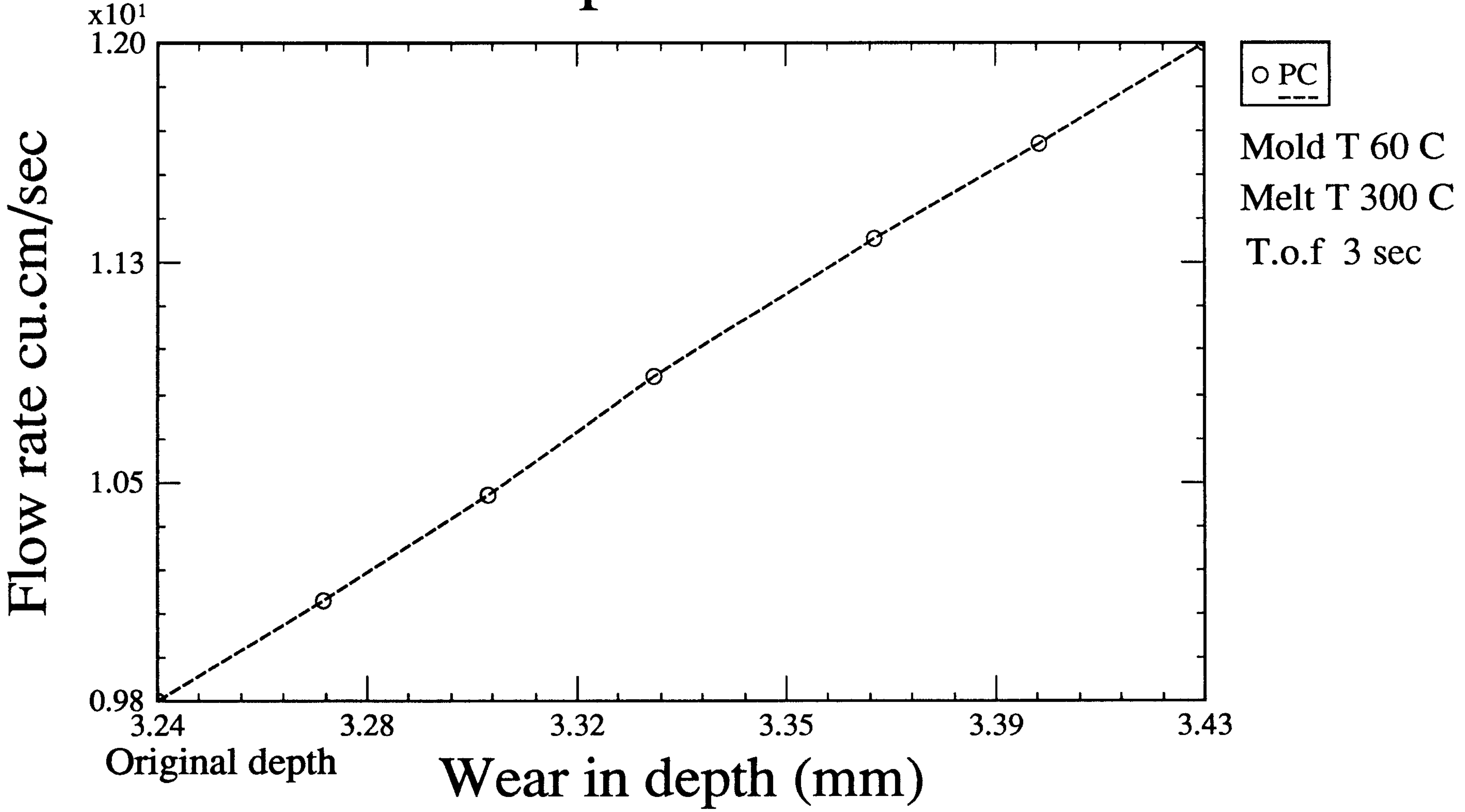
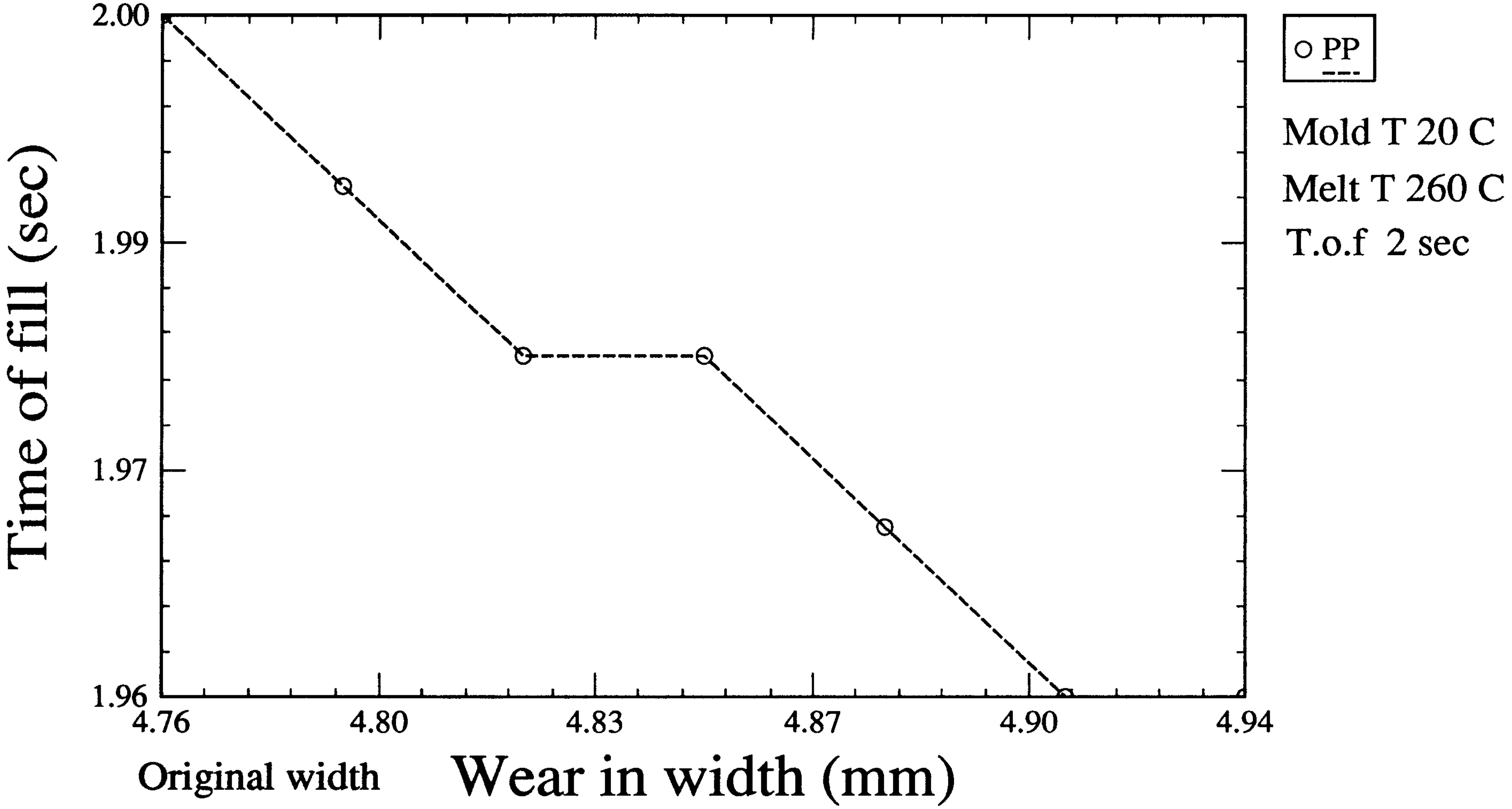


Fig 4.52

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:20:50 1991 (data file was /usr/tmp/TG.AAAa04328)



Wear in width vs Time of fill

Fig. 4.53

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:54:18 1991 (data file was /usr/tmp/TG.AAAa04328)

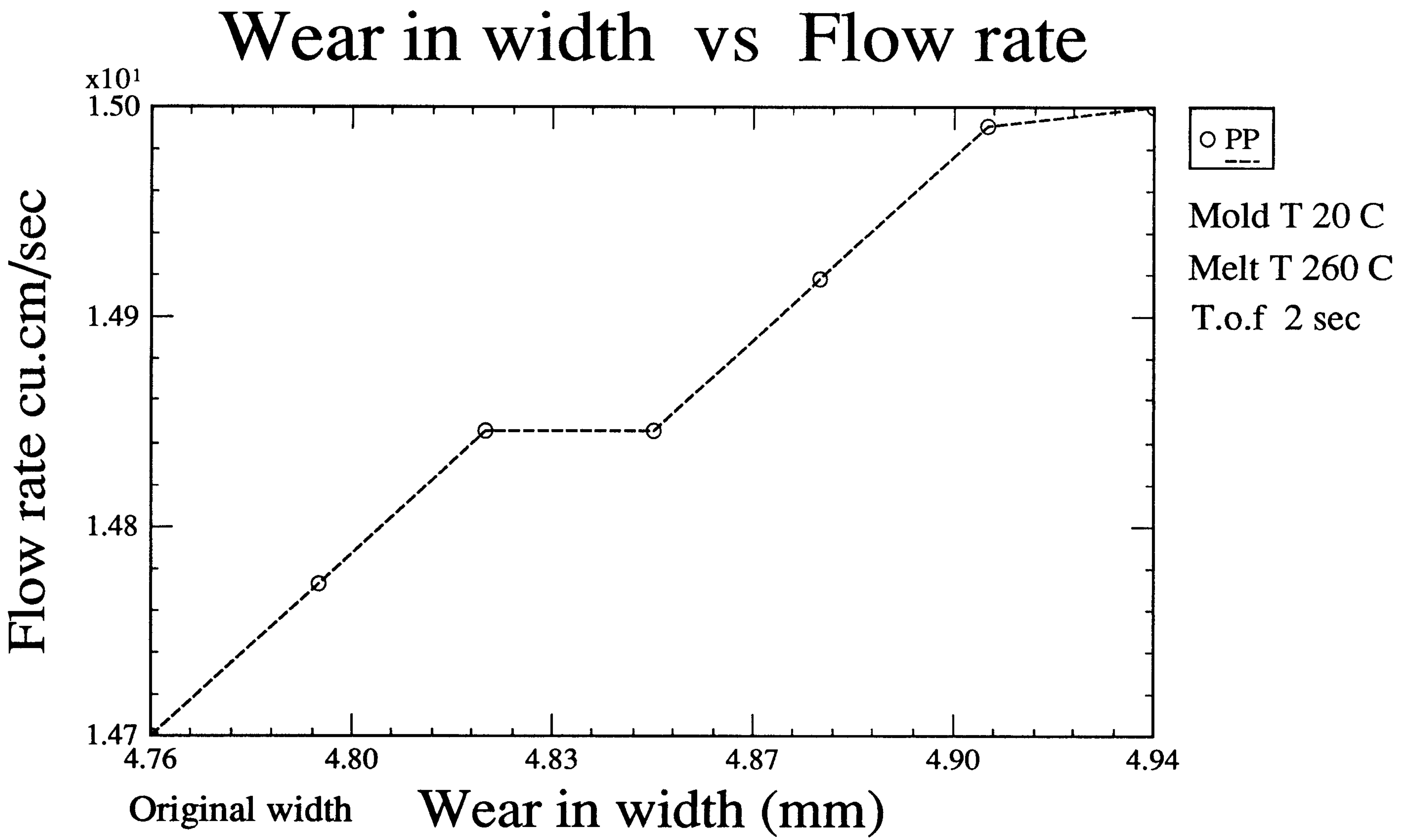


Fig. 4.54

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 19:46:13 1991 (data file was /usr/tmp/TG.AAAa04328)

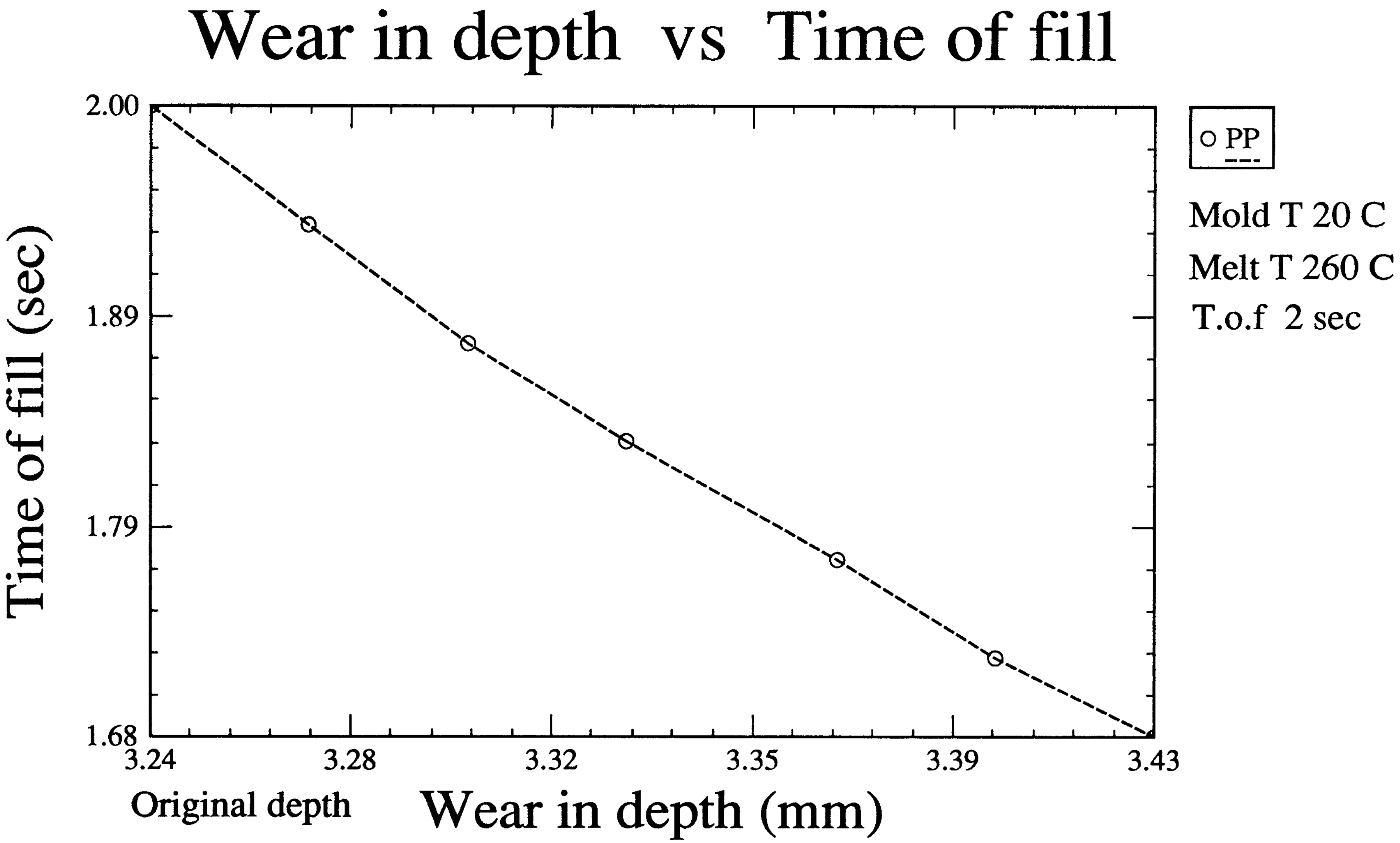


Fig. 4.55

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 20:09:42 1991 (data file was /usr/tmp/TG.AAAa04328)

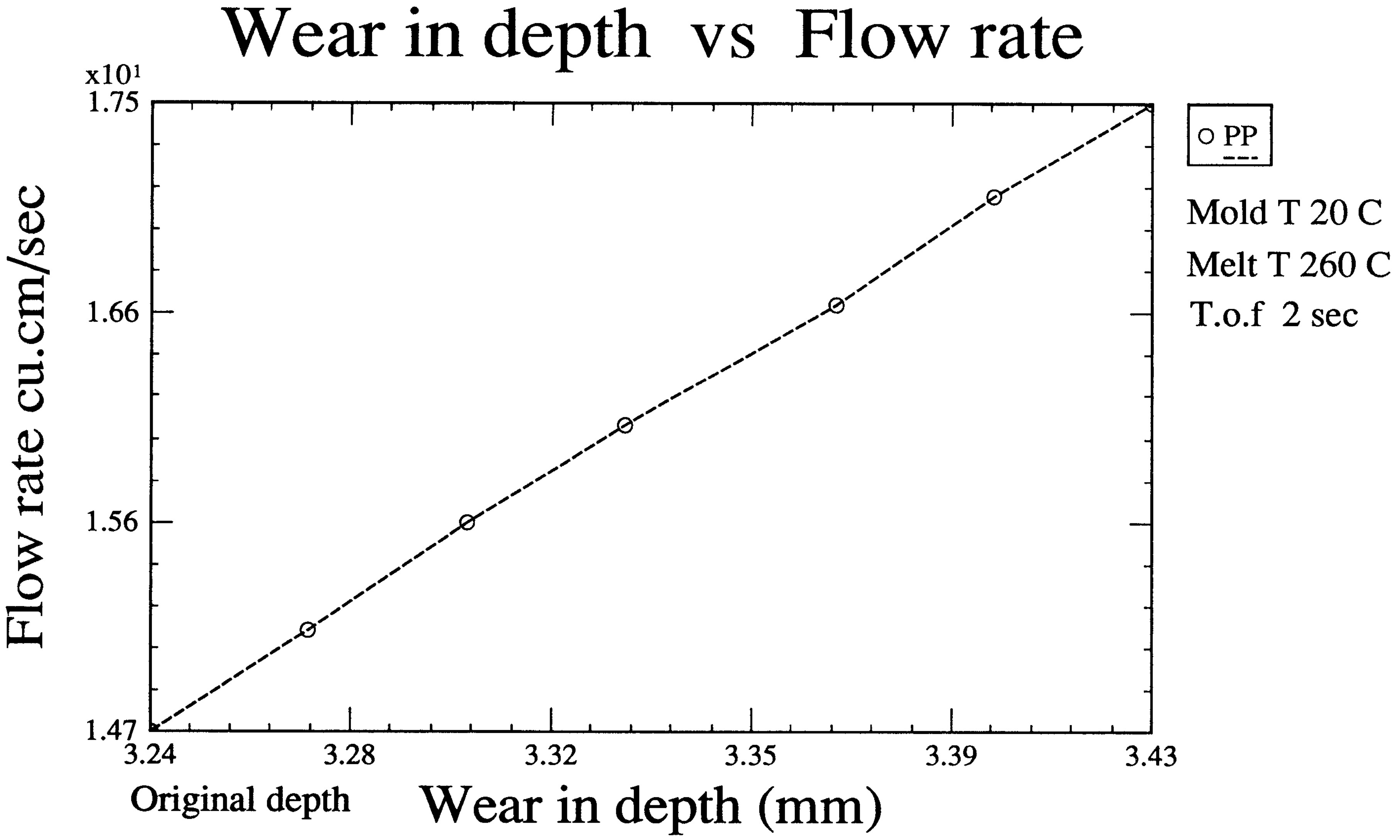


Fig. 4.56

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 20:13:42 1991 (data file was /usr/tmp/TG.AAAa04328)

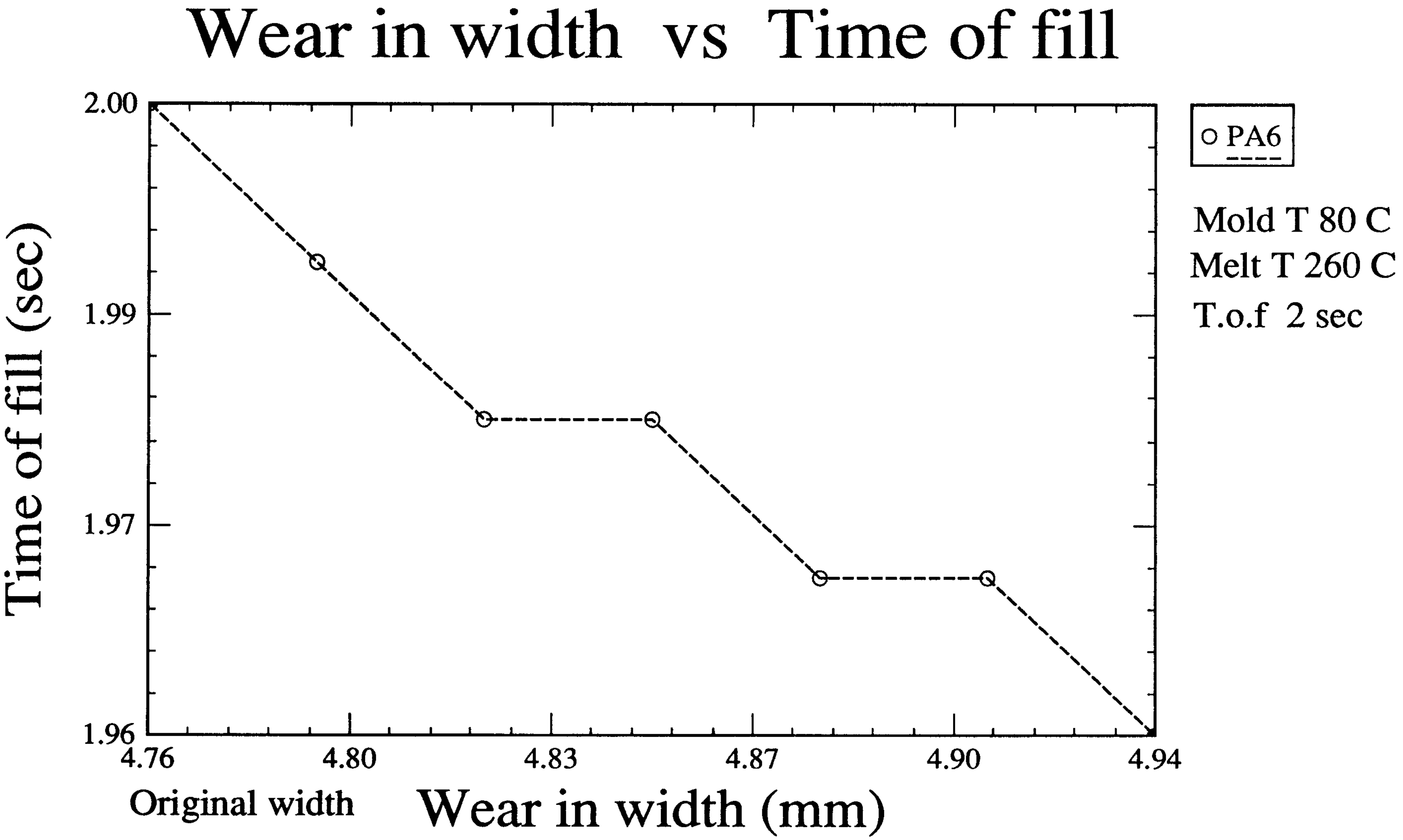


Fig. 4.57

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 20:26:10 1991 (data file was /usr/tmp/TG.AAAa04328)

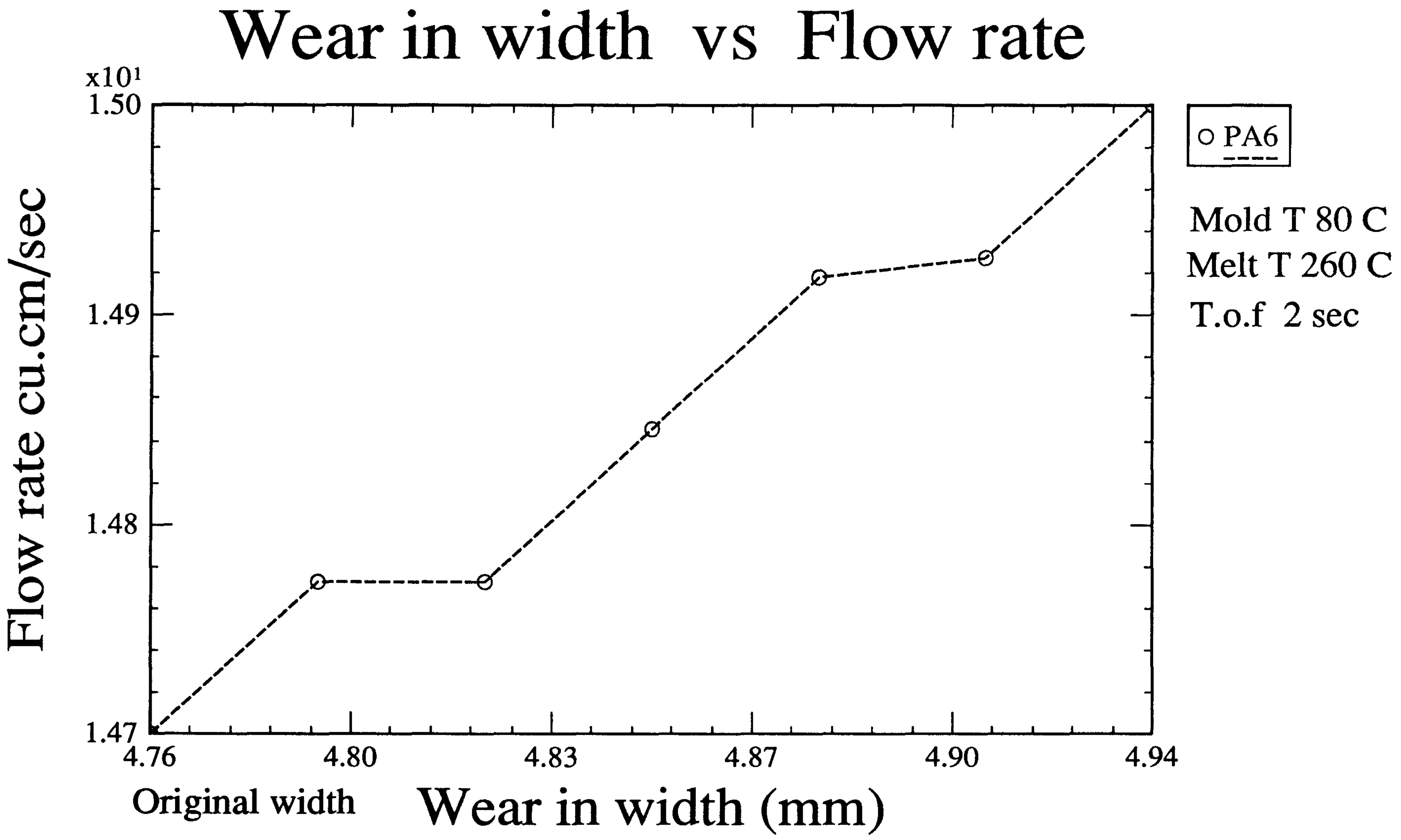


Fig. 4.58

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 20:21:23 1991 (data file was /usr/tmp/TG.AAAa04328)

Wear in depth vs Time of fill

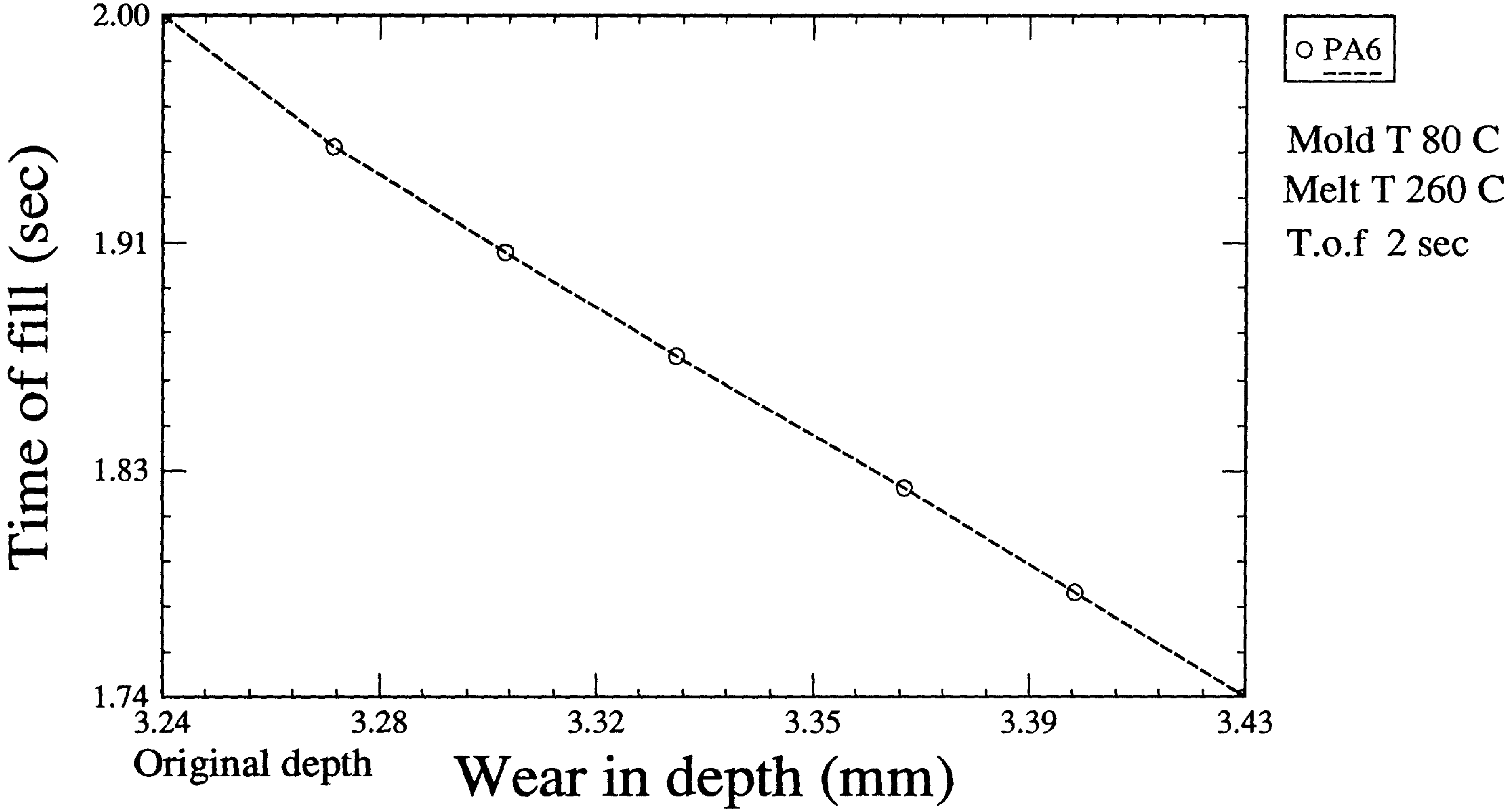


Fig. 4.59

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw54 - Thu May 2 20:32:16 1991 (data file was /usr/tmp/TG.AAAa04328)

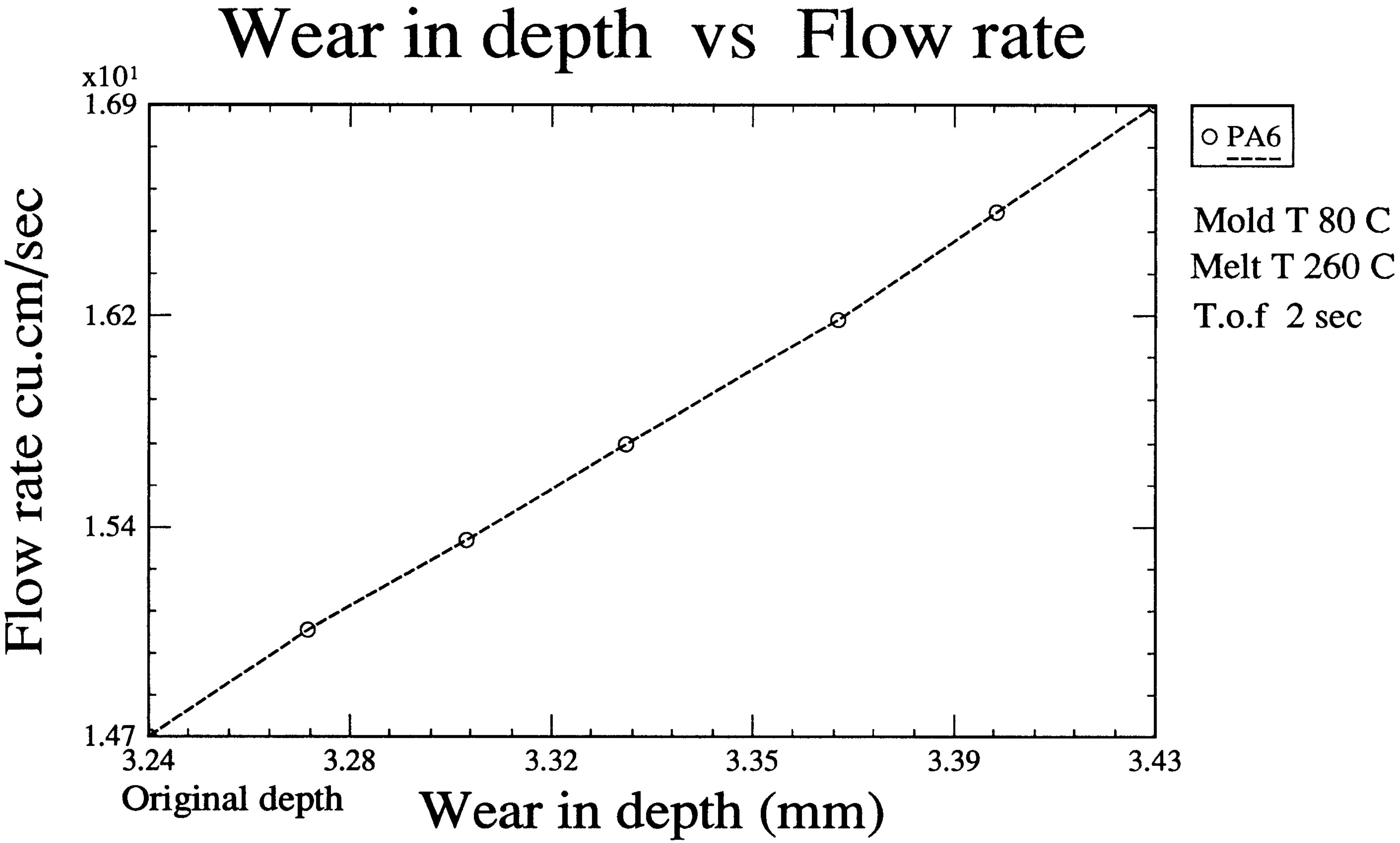

Wear in depth vs Flow rate
x10¹
1.69
1.62
1.54
1.47
Flow rate cu.cm/sec
3.24
3.28
3.32
3.35
3.39
3.43
Original depth
Wear in depth (mm)
○ PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.60

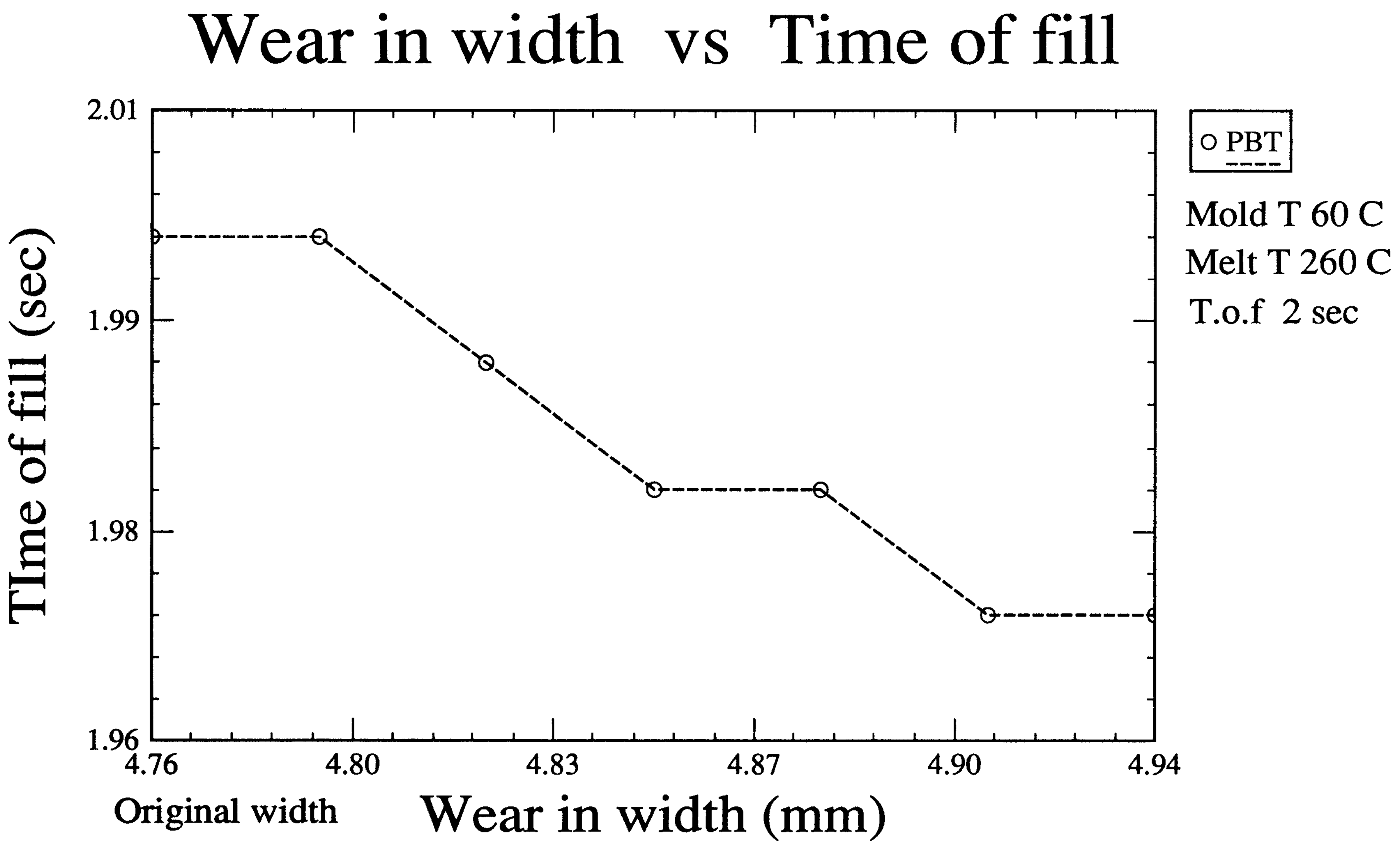

Wear in width vs Time of fill
TIme of fill (sec)
2.01
1.99
1.98
1.96
4.76
4.80
4.83
4.87
4.90
4.94
Original width
Wear in width (mm)
○ PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.61

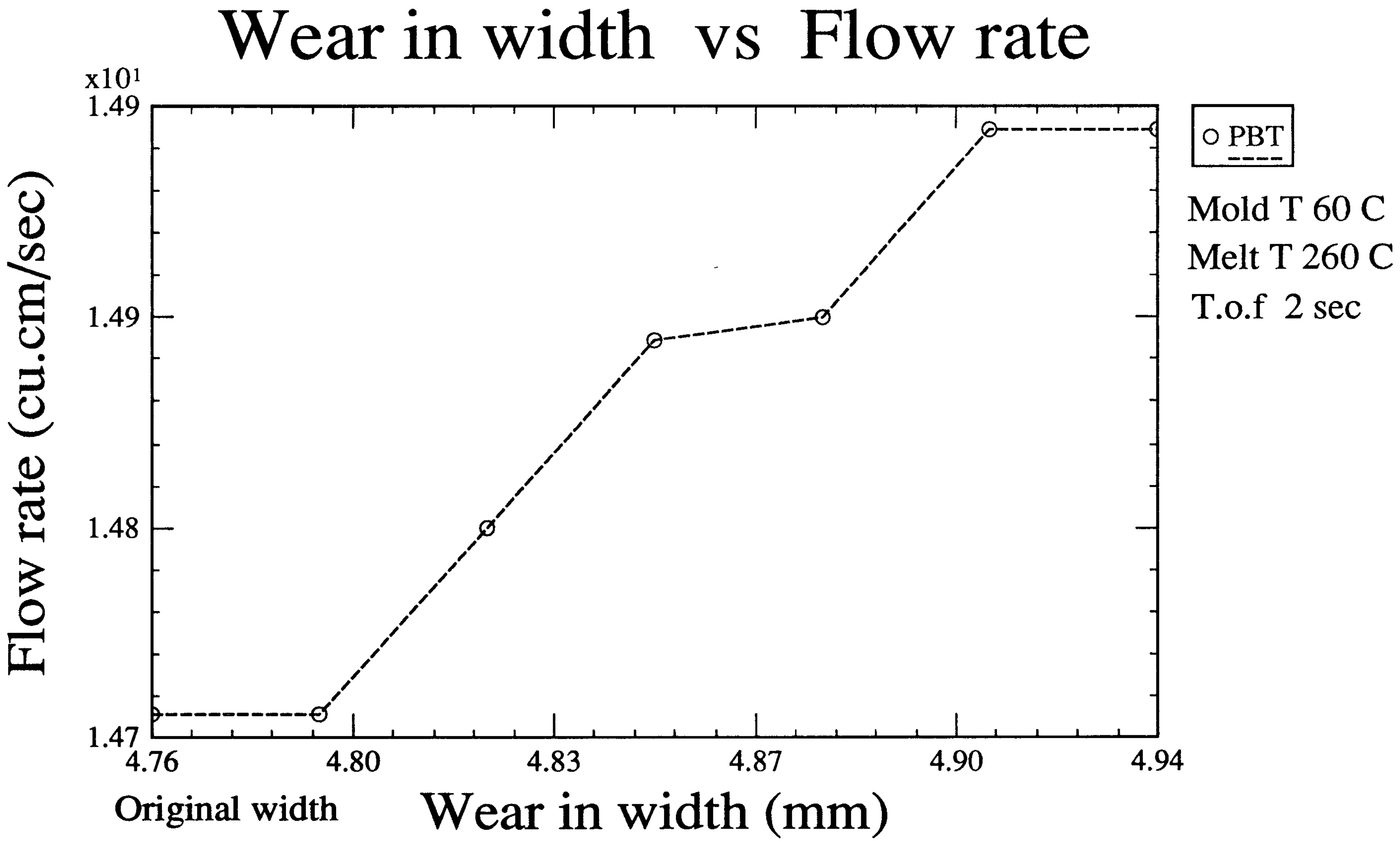

Wear in width vs Flow rate

FIg. 4.62

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 09:43:44 1991 (data file was /usr/tmp/TG.AAAa15007)

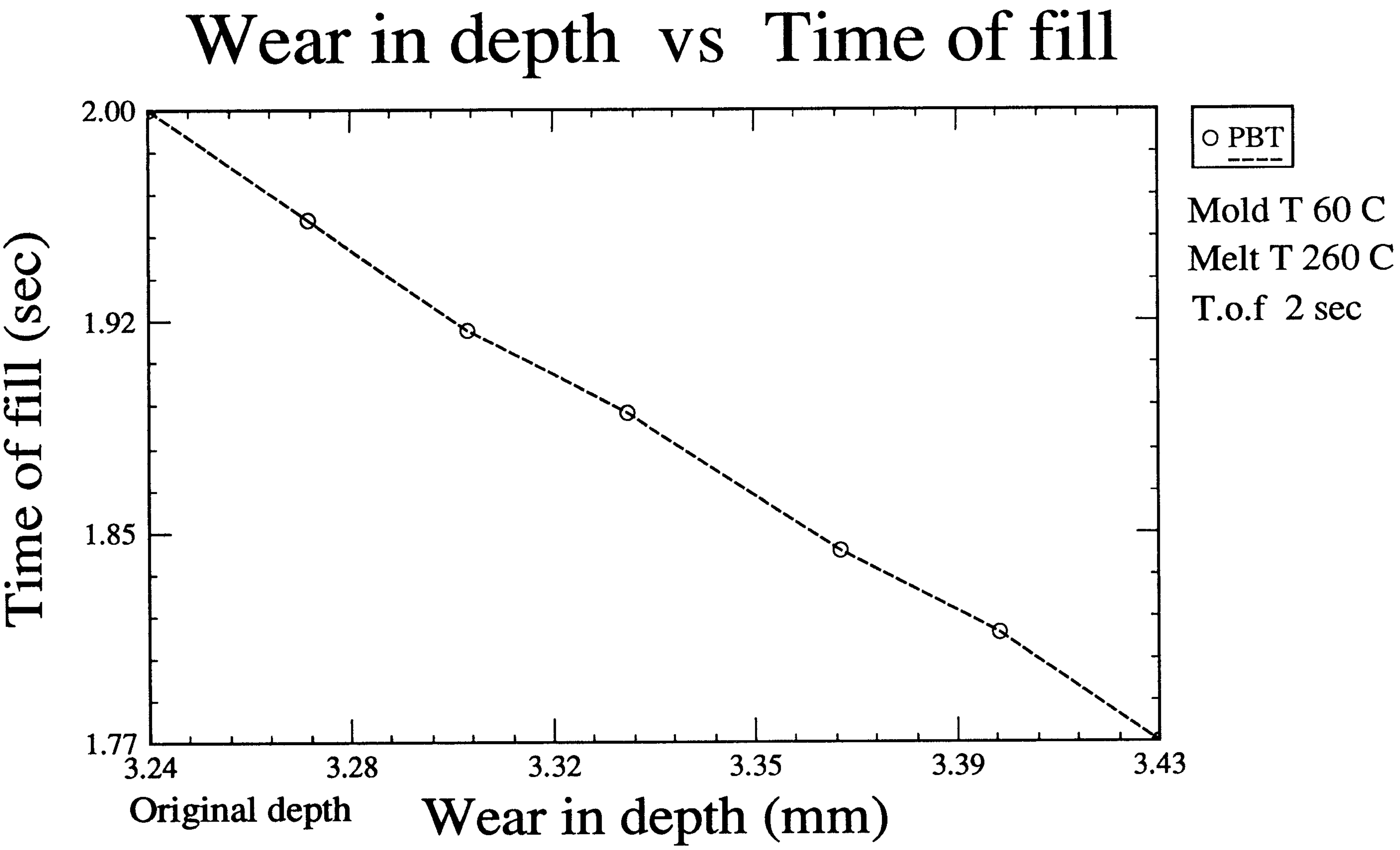


Fig. 4.63

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 10:08:12 1991 (data file was /usr/tmp/TG.AAAa15007)

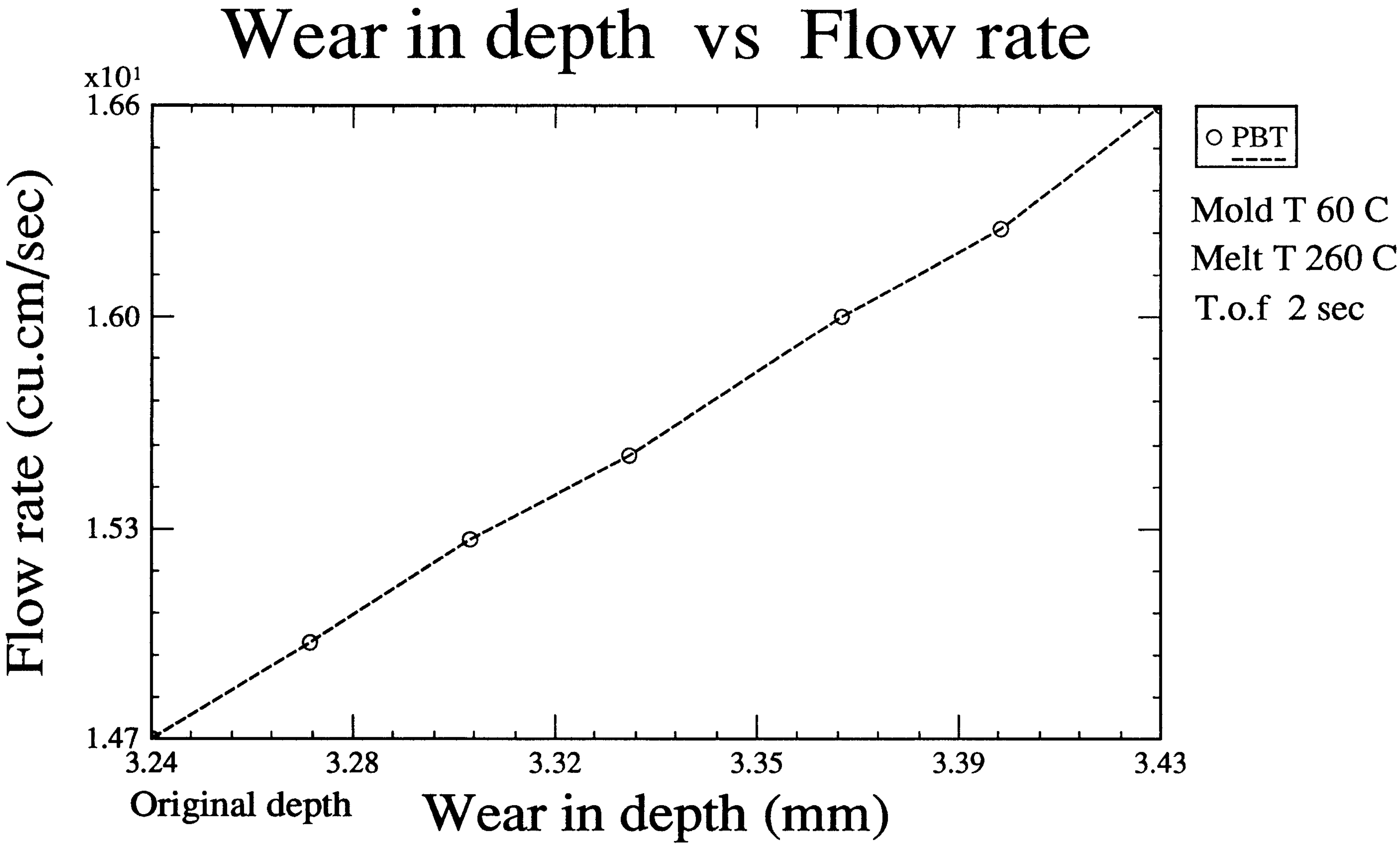
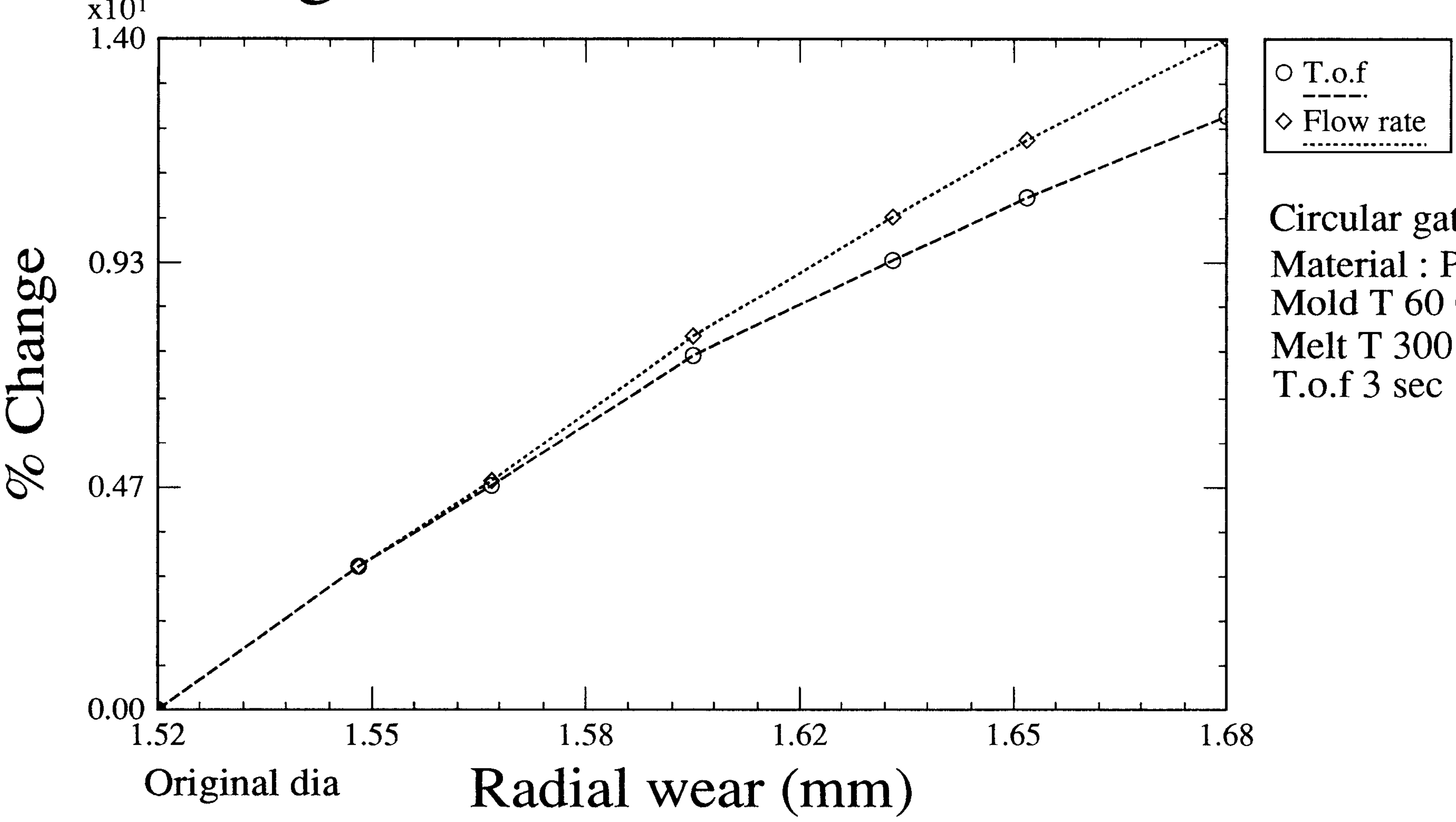


Fig. 4.64

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw57 - Fri May 3 09:55:53 1991 (data file was /usr/tmp/TG.AAAa15007)



Circular gate
Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.65

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:23:14 1991 (data file was 4.65.data)

% change in T.o.f & F.r for radial wear

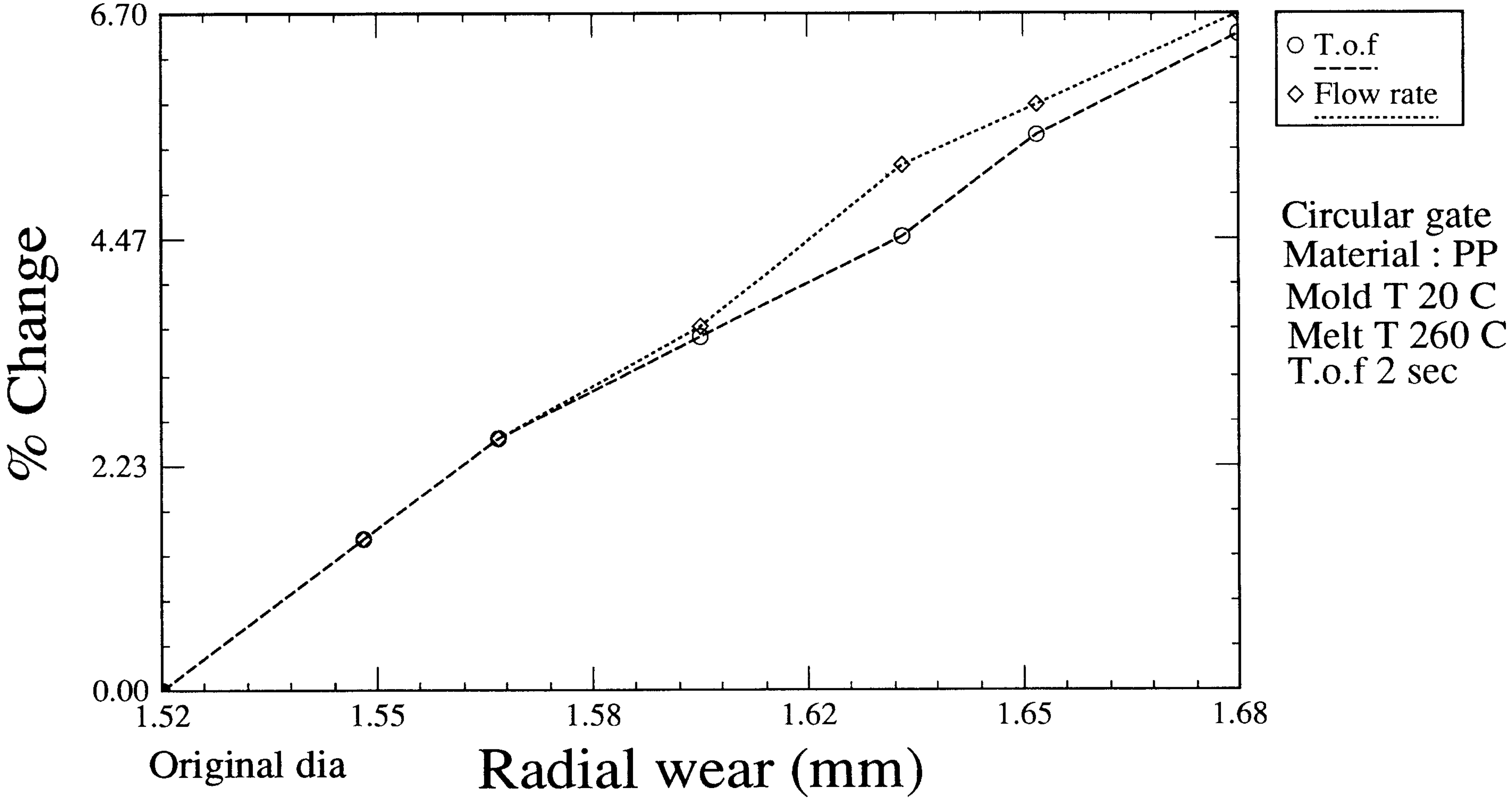


Fig. 4.66

TempleGraph 2.3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:16·27 1991 (data file was /usr/mesuna/users/rva3859/4 66.data)

% change in T.o.f & F.r for radial wear

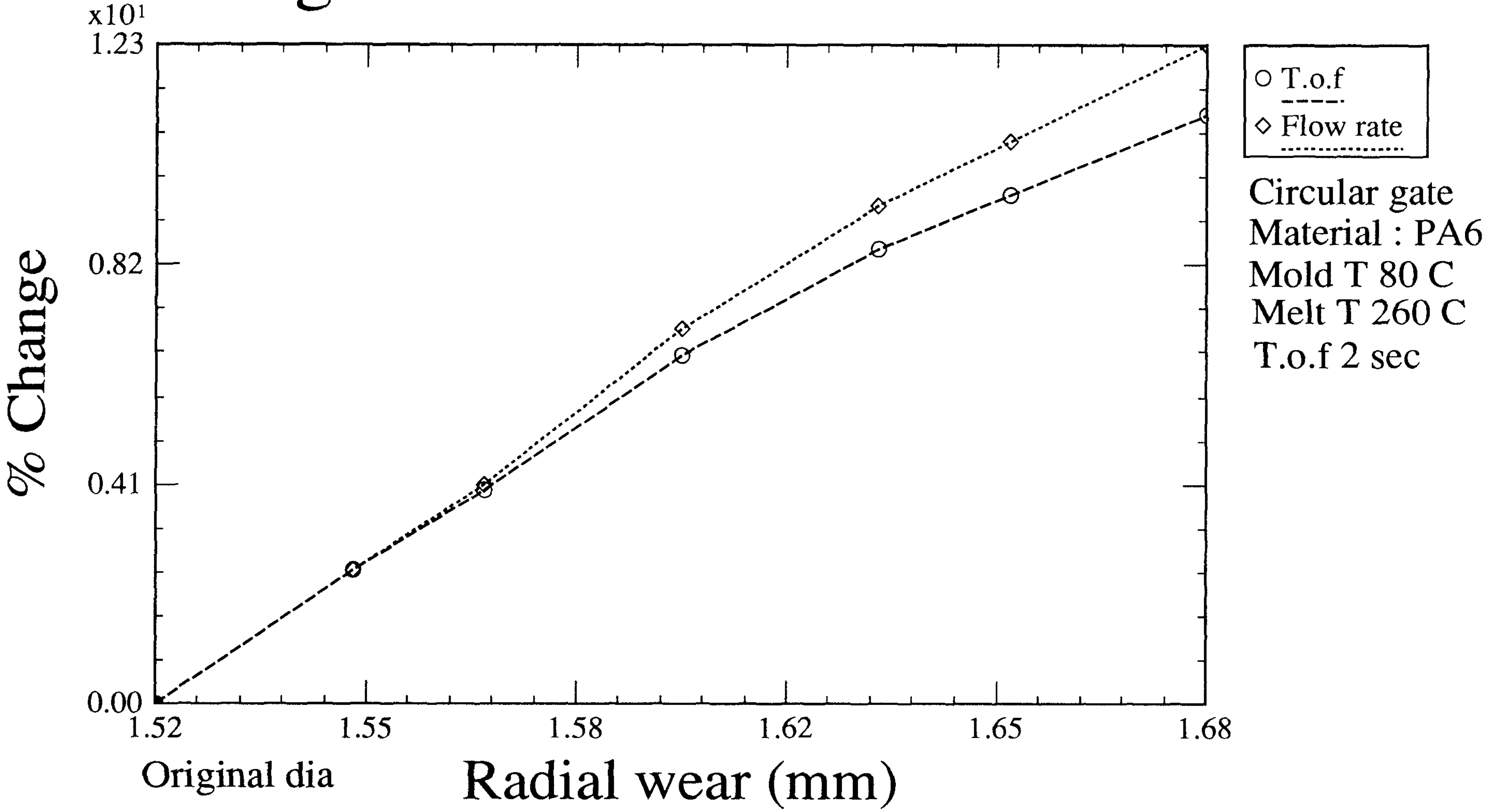
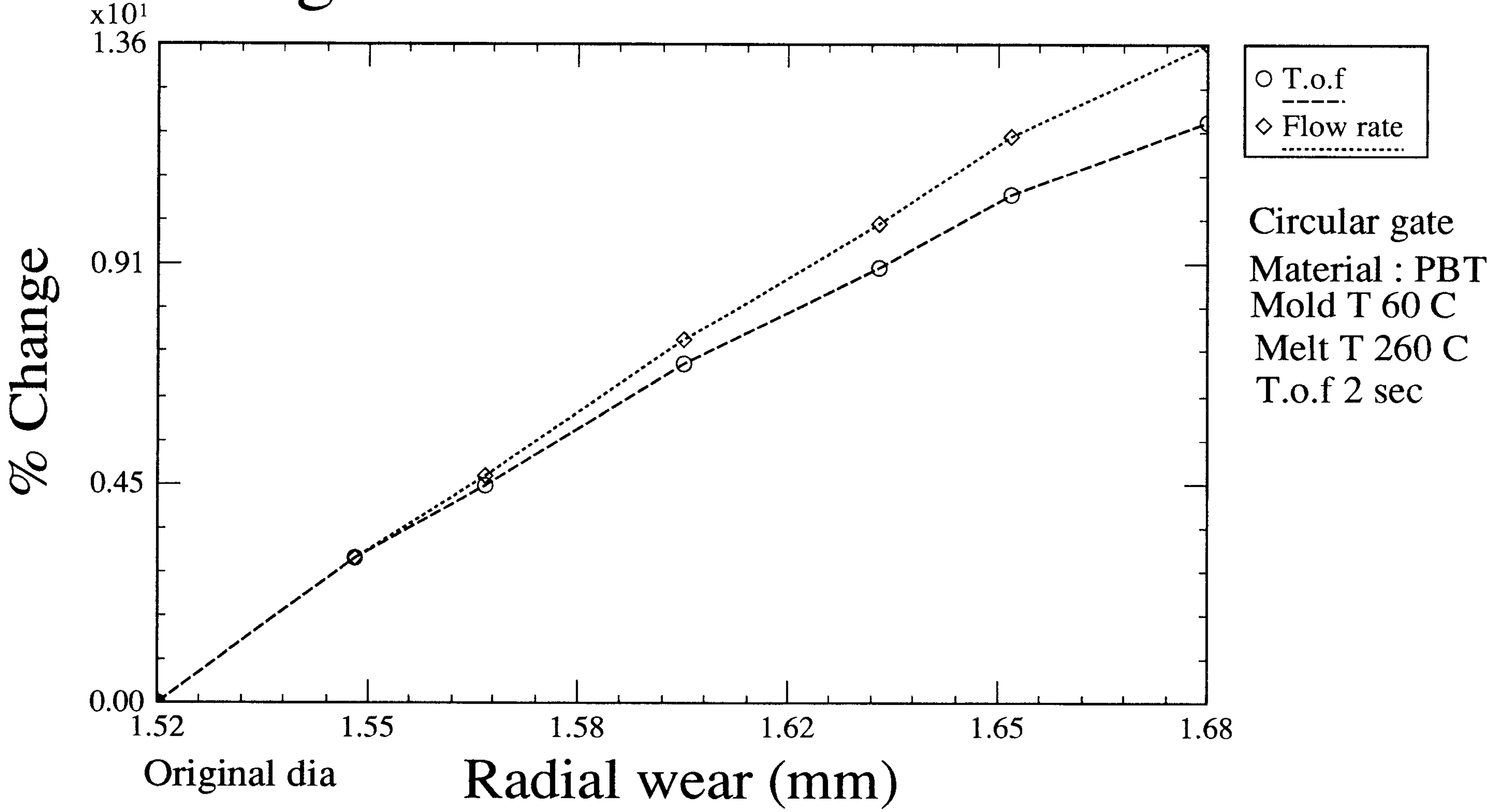


Fig. 4.67

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21 07 55 1991 (data file was /usr/tmp/TG.AAAa20297)

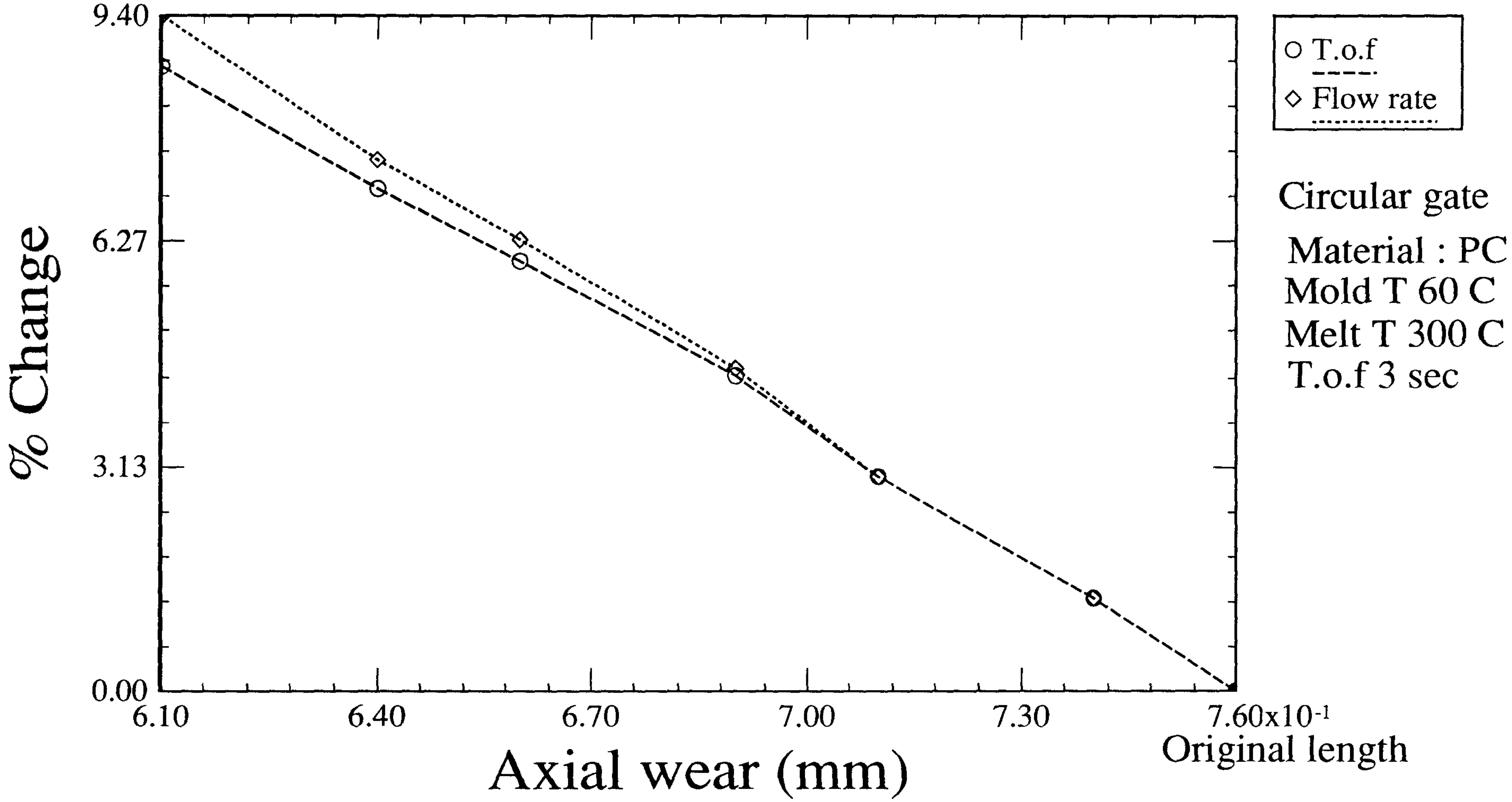
% change in T.o.f & F.r for radial wear



Circular gate
Material : PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig 4.68

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:29:17 1991 (data file was /usr/tmp/TG.AAAa20297)

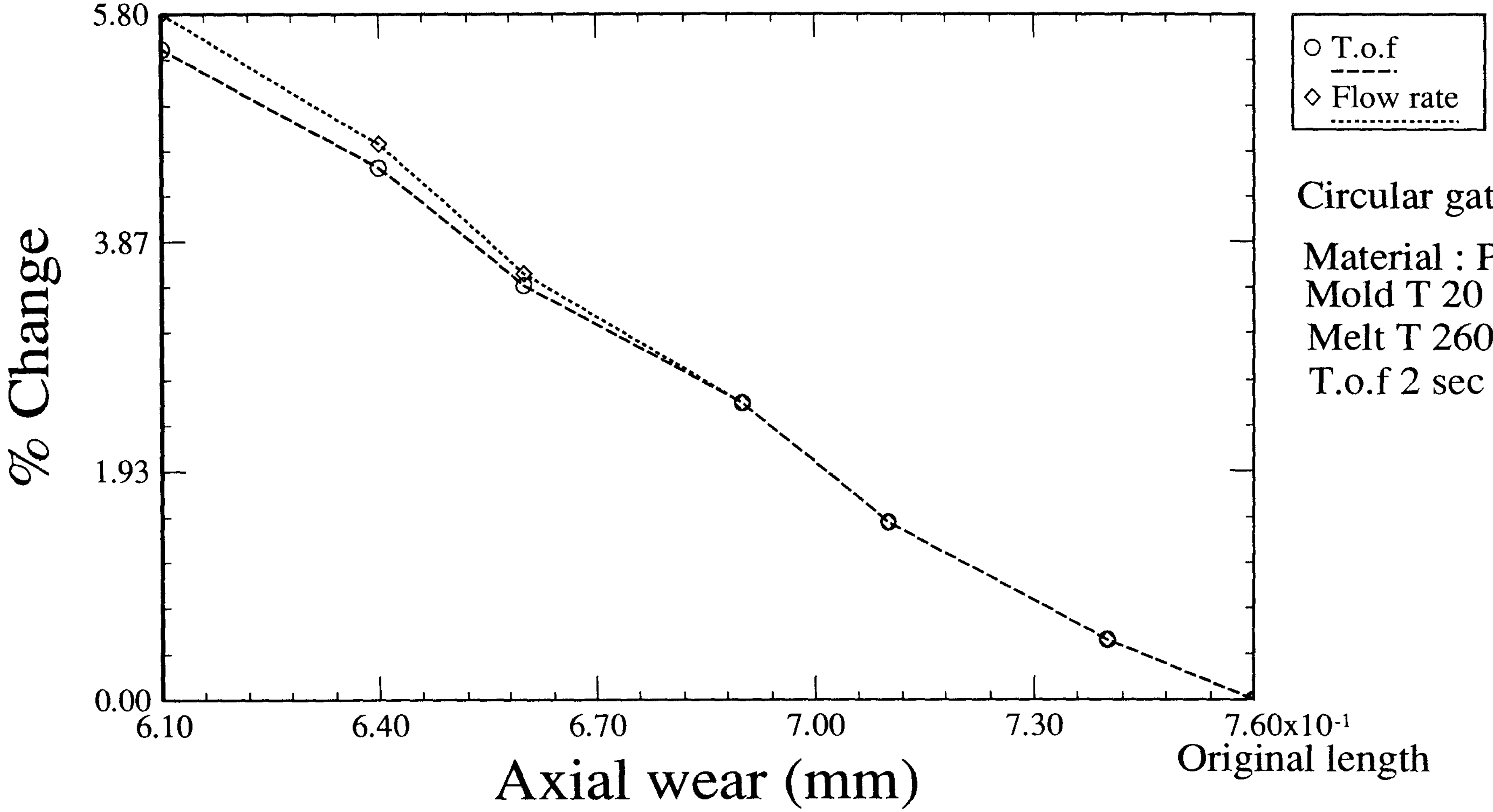


% change in T.o.f & F.r for axial wear

Fig. 4.69

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21·40:58 1991 (data file was /usr/tmp/TG AAAa20297)

% change in T.o.f & F.r for axial wear



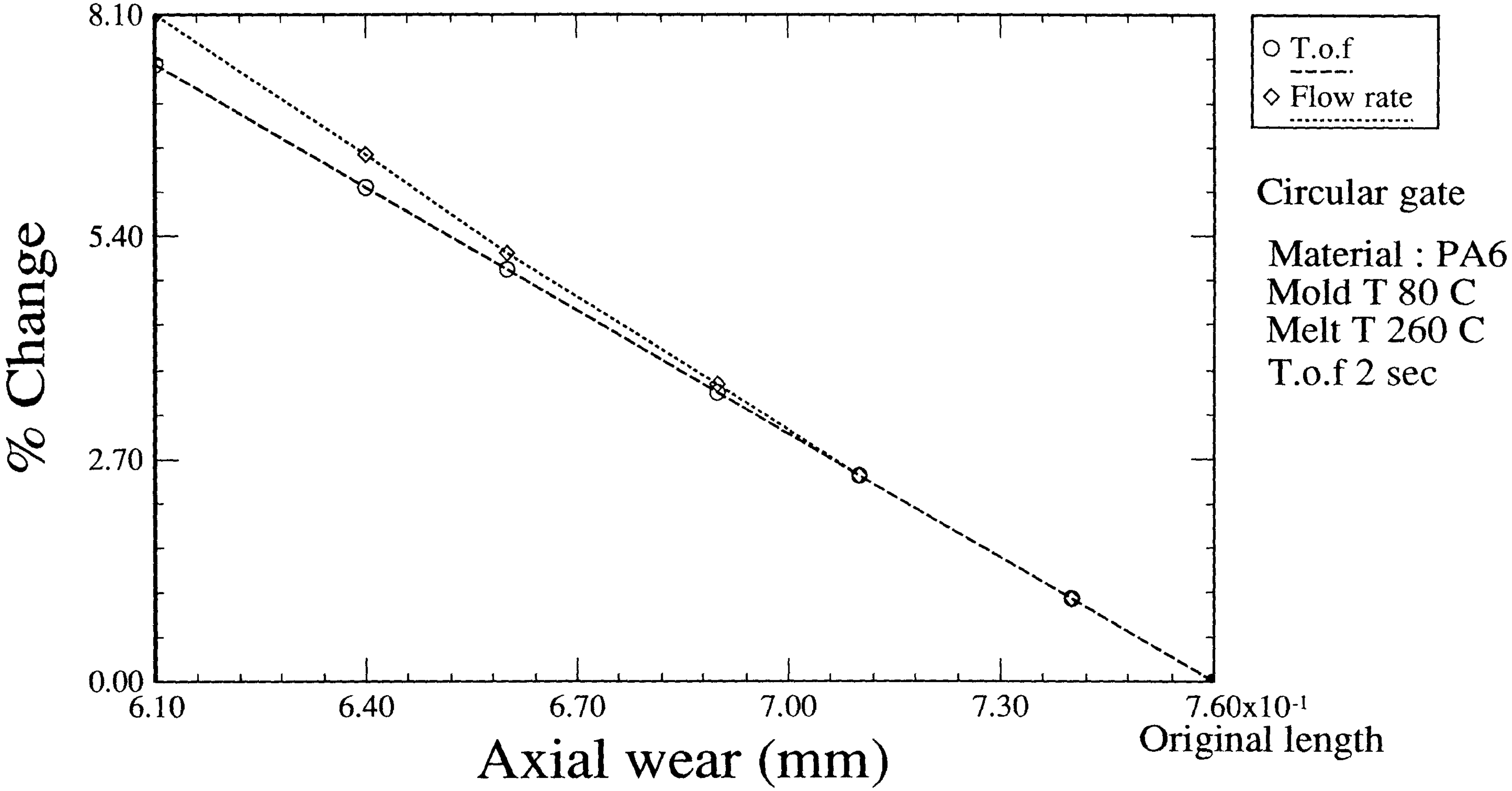
Circular gate

Material : PP
Mold T 20 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.70

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:46:39 1991 (data file was /usr/tmp/TG AAAa20297)

% change in T.o.f & F.r for axial wear



Circular gate

Material : PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.71

TempleGraph 2.3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:50·49 1991 (data file was /usr/tmp/TG.AAAa20297)

% change in T.o.f & F.r for axial wear

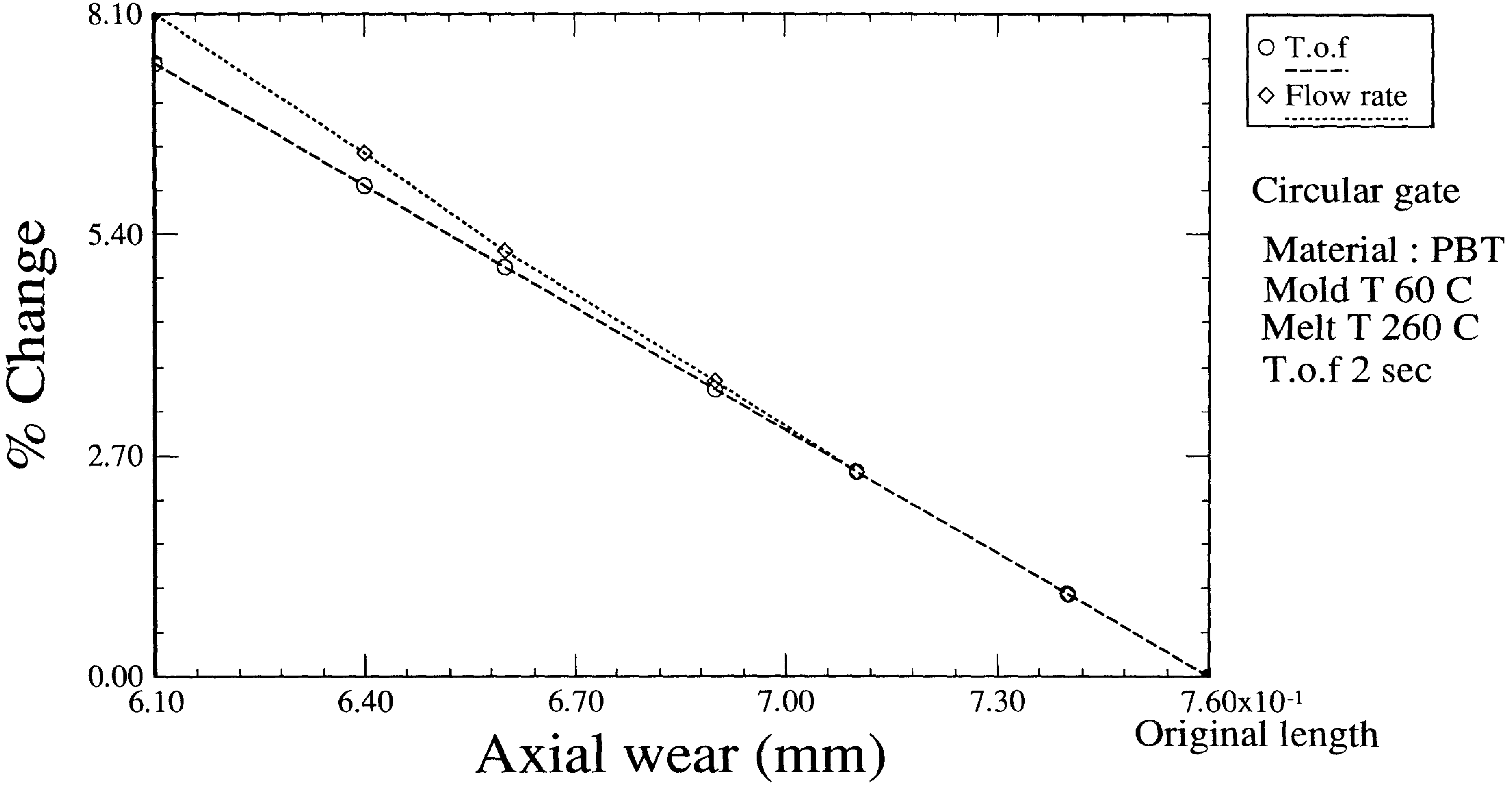
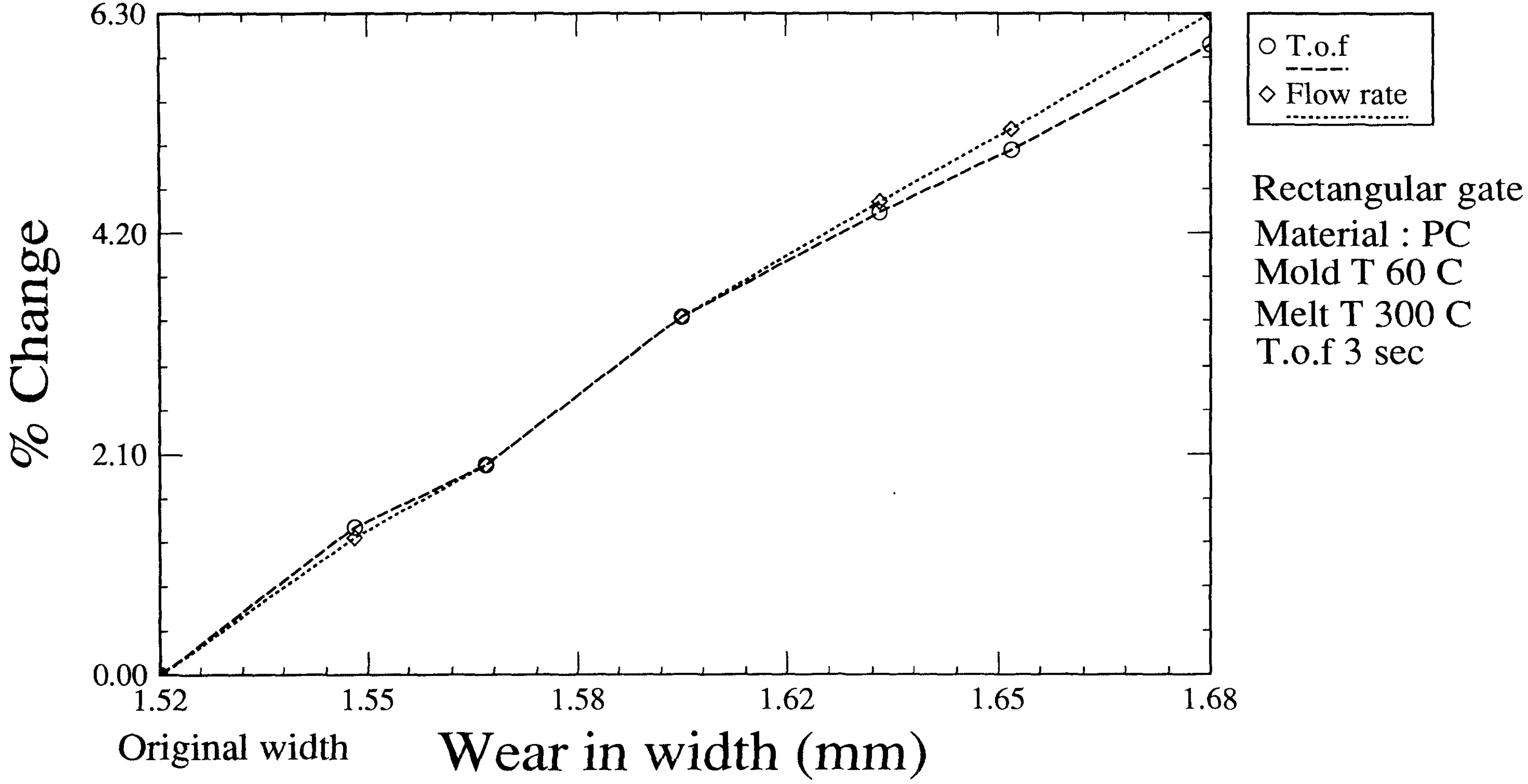


Fig. 4.72

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 21:55:18 1991 (data file was /usr/tmp/TG.AAAa20297)

% change in T.o.f & F.r for wear in width



Rectangular gate
Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.73

TempleGraph 2 3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 09 26 17 1991 (data file was /usr/tmp/TG AAAa21827)

% change in T.o.f & F.r for wear in width

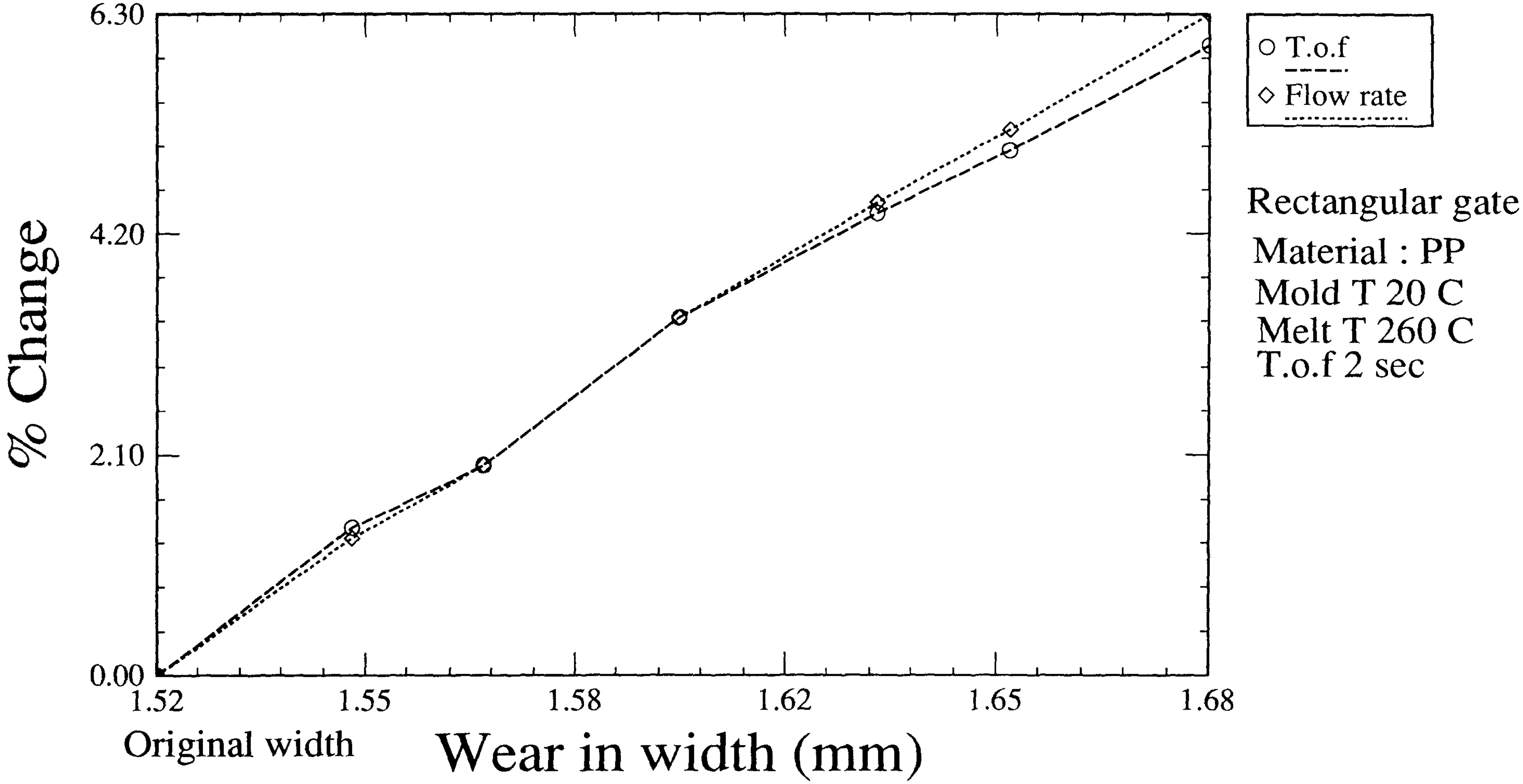
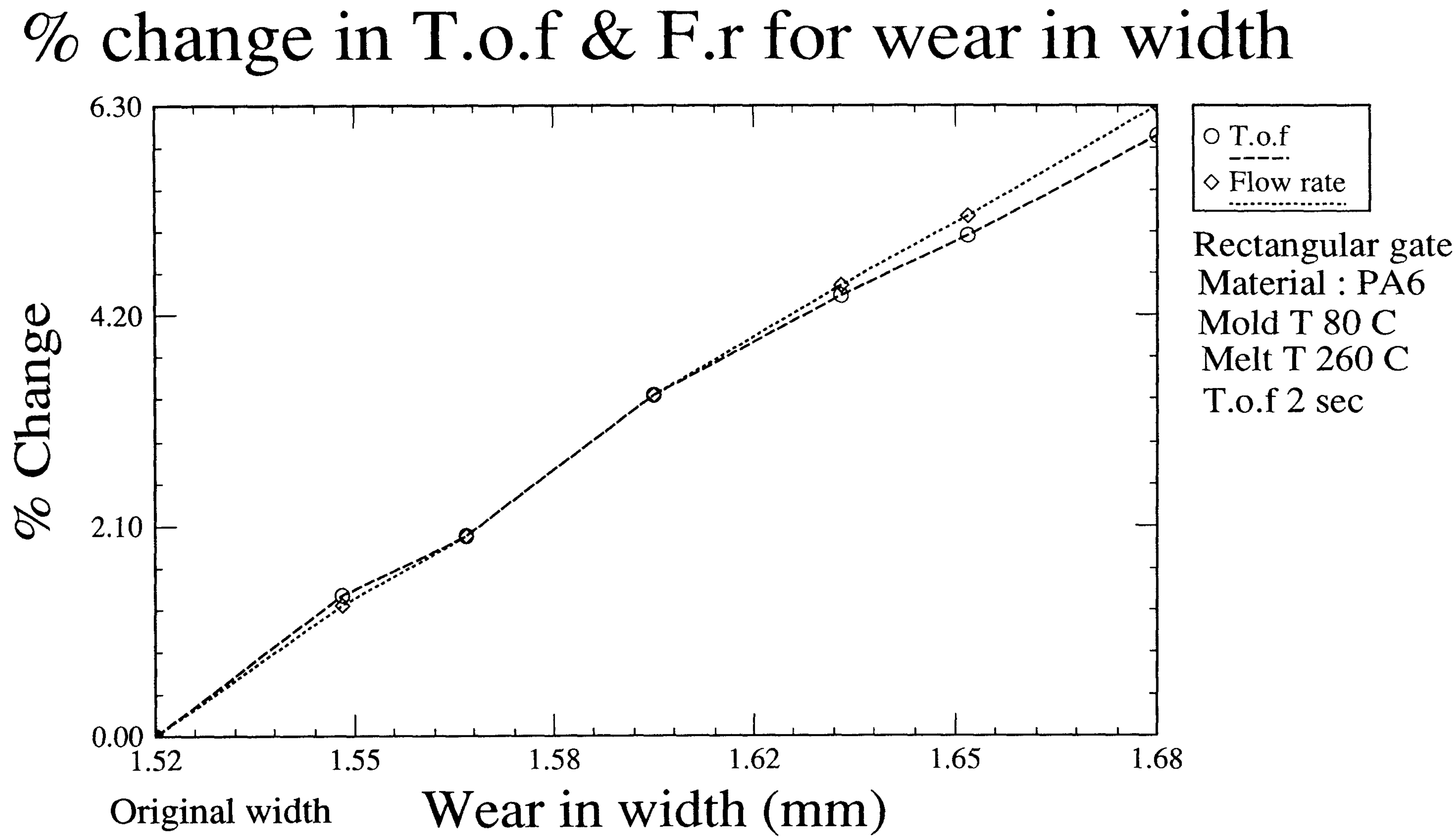


Fig. 4.74

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 09 31 07 1991 (data file was /usr/tmp/TG.AAAa21827)



Rectangular gate
Material : PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.75

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 09:49·51 1991 (data file was /usr/tmp/TG.AAAa21827)

% change in T.o.f & F.r for wear in width

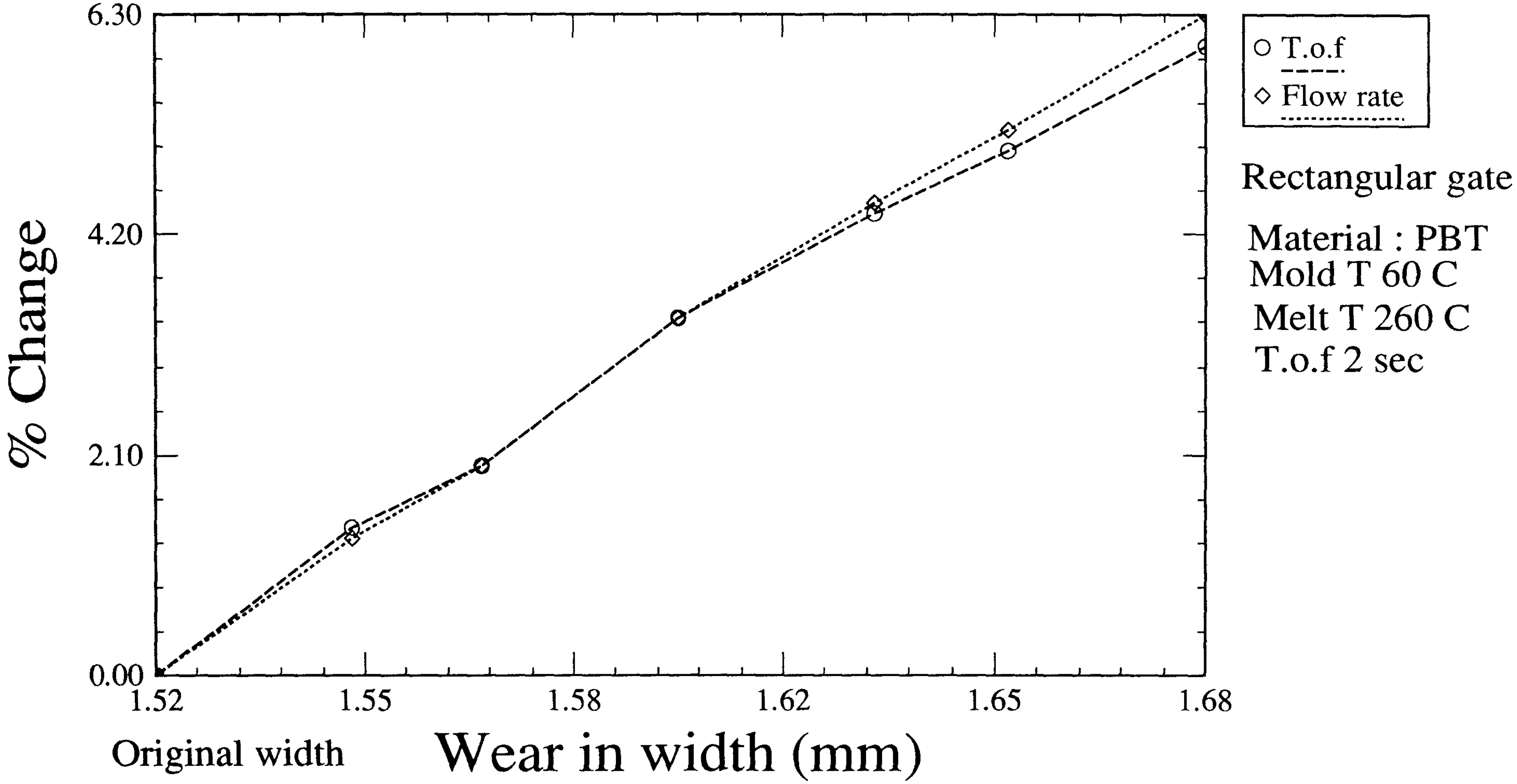
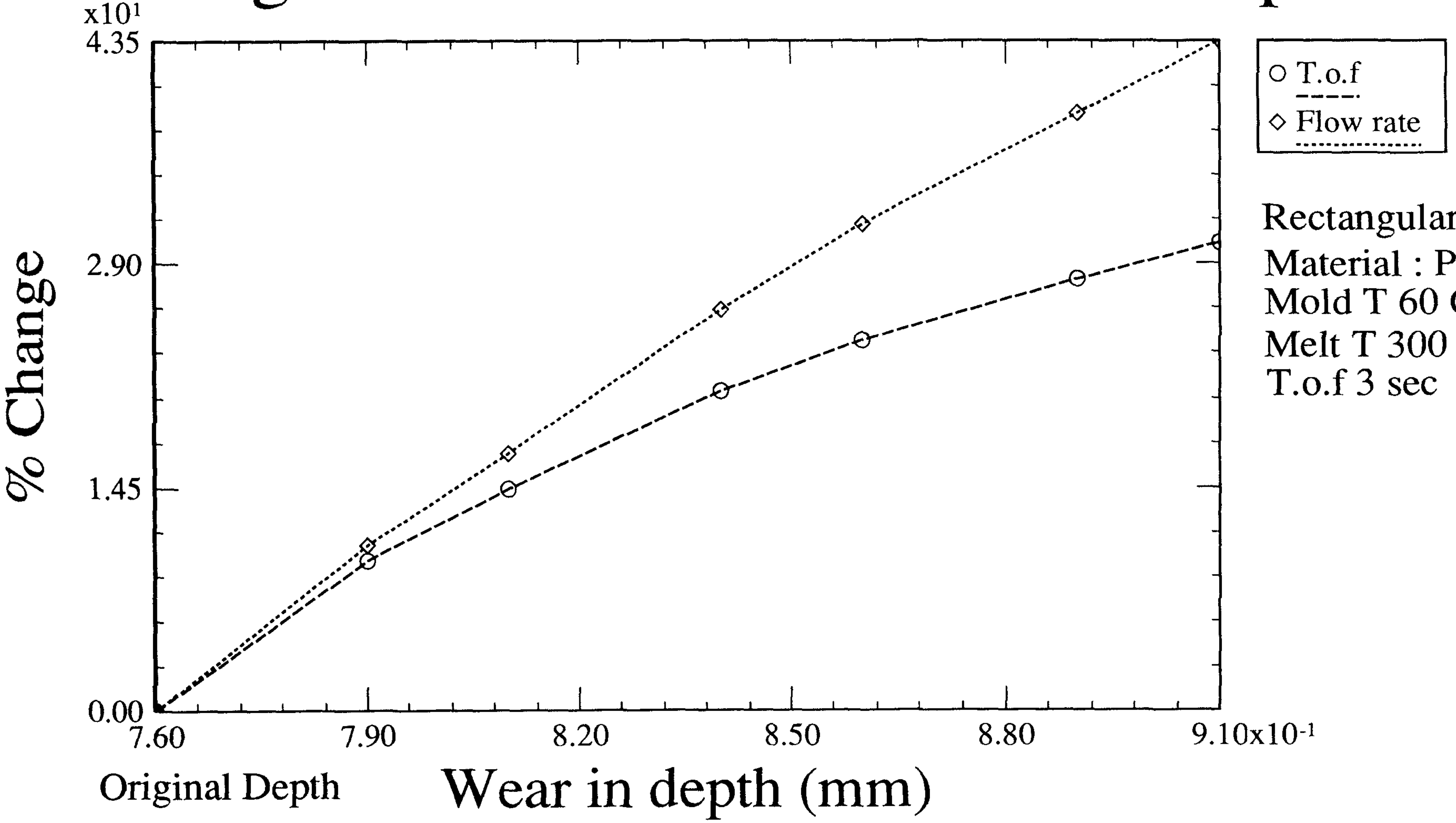


Fig. 4.76

TempleGrapl. , Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 09:55·02 1991 (file was /usr/tmp/TG.AAAa21827)

% change in T.o.f & F.r for wear in depth



Rectangular gate
Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.77

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 10:02:31 1991 (data file was /usr/tmp/TG AAAa21827)

% change in T.o.f & F.r for wear in depth

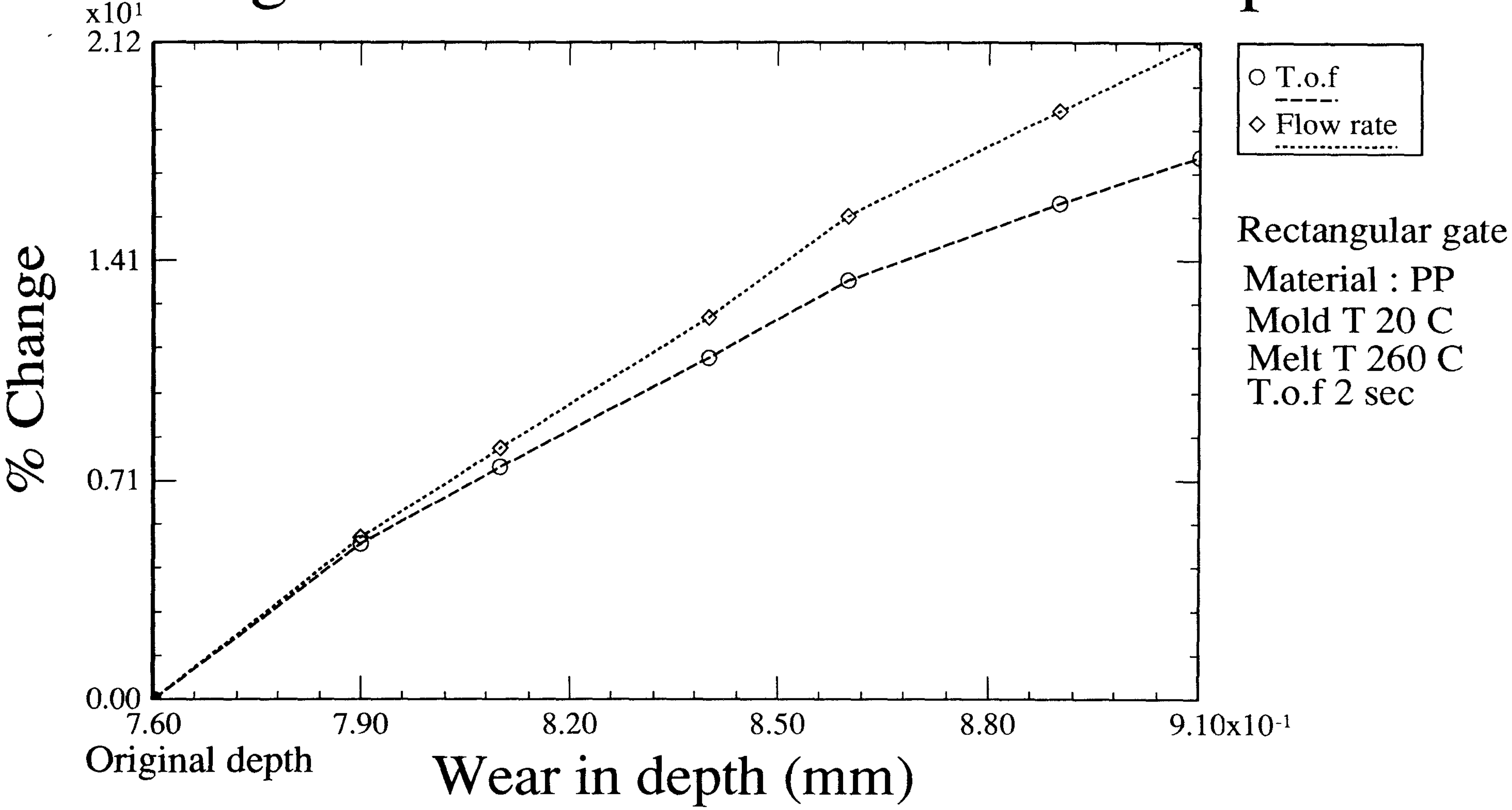


Fig. 4.78

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 10 08 25 1991 (data file was /usr/tmp/TG.AAAa21827)

% change in T.o.f & F.r for wear in depth

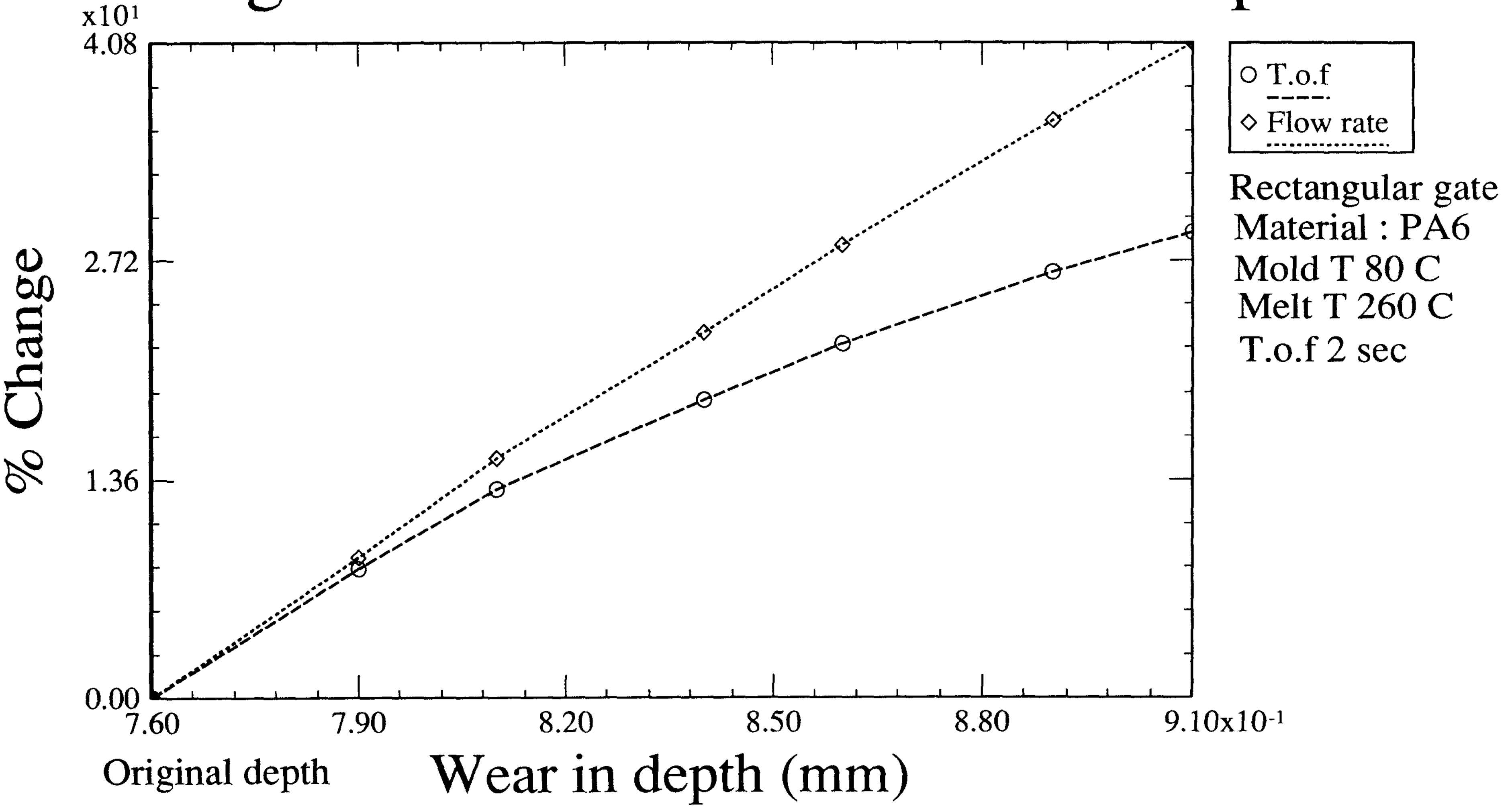
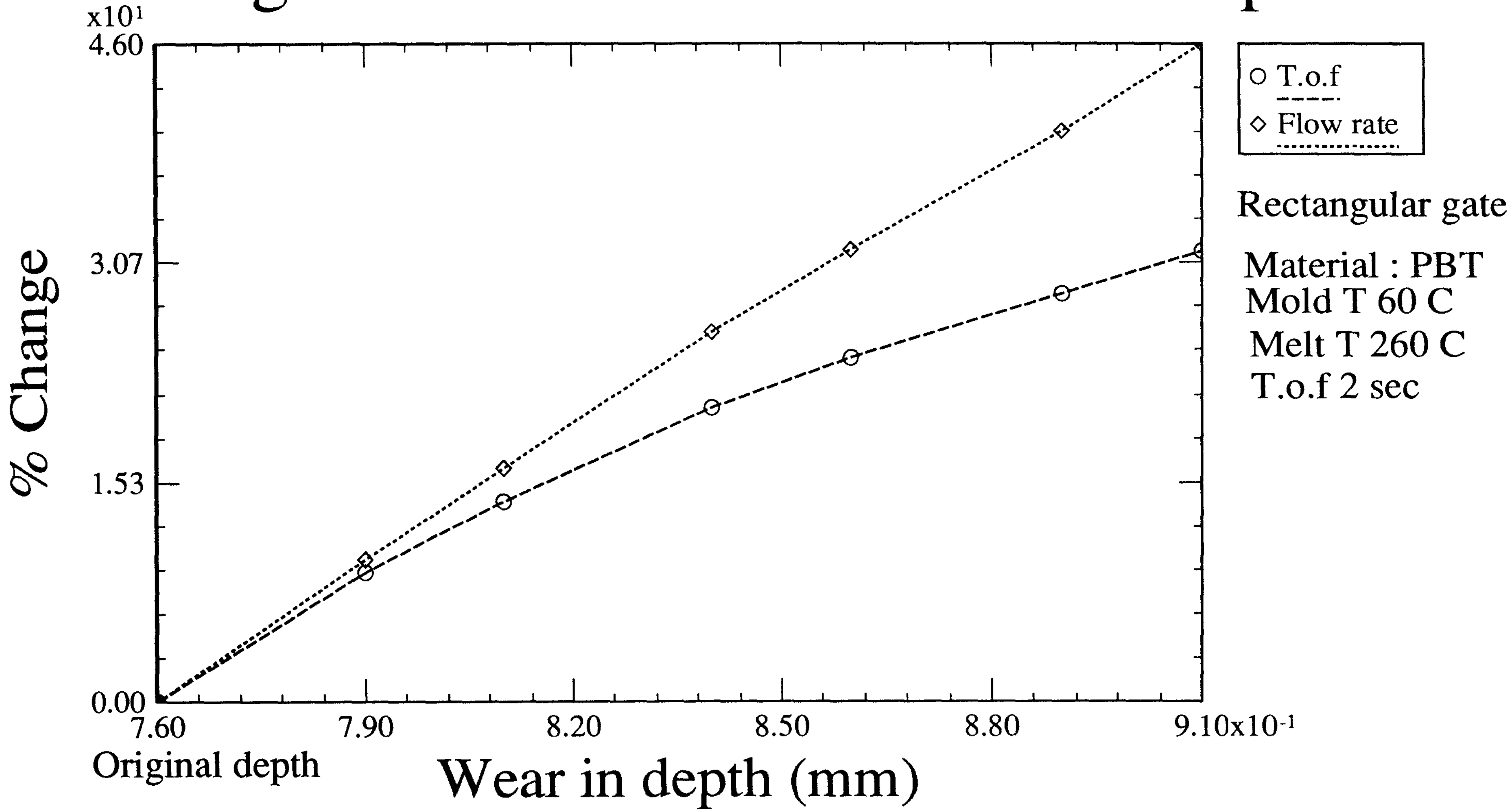


Fig. 4.79

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 10 19:49 1991 (data file was /usr/tmp/TG AAAa21827)

% change in T.o.f & F.r for wear in depth



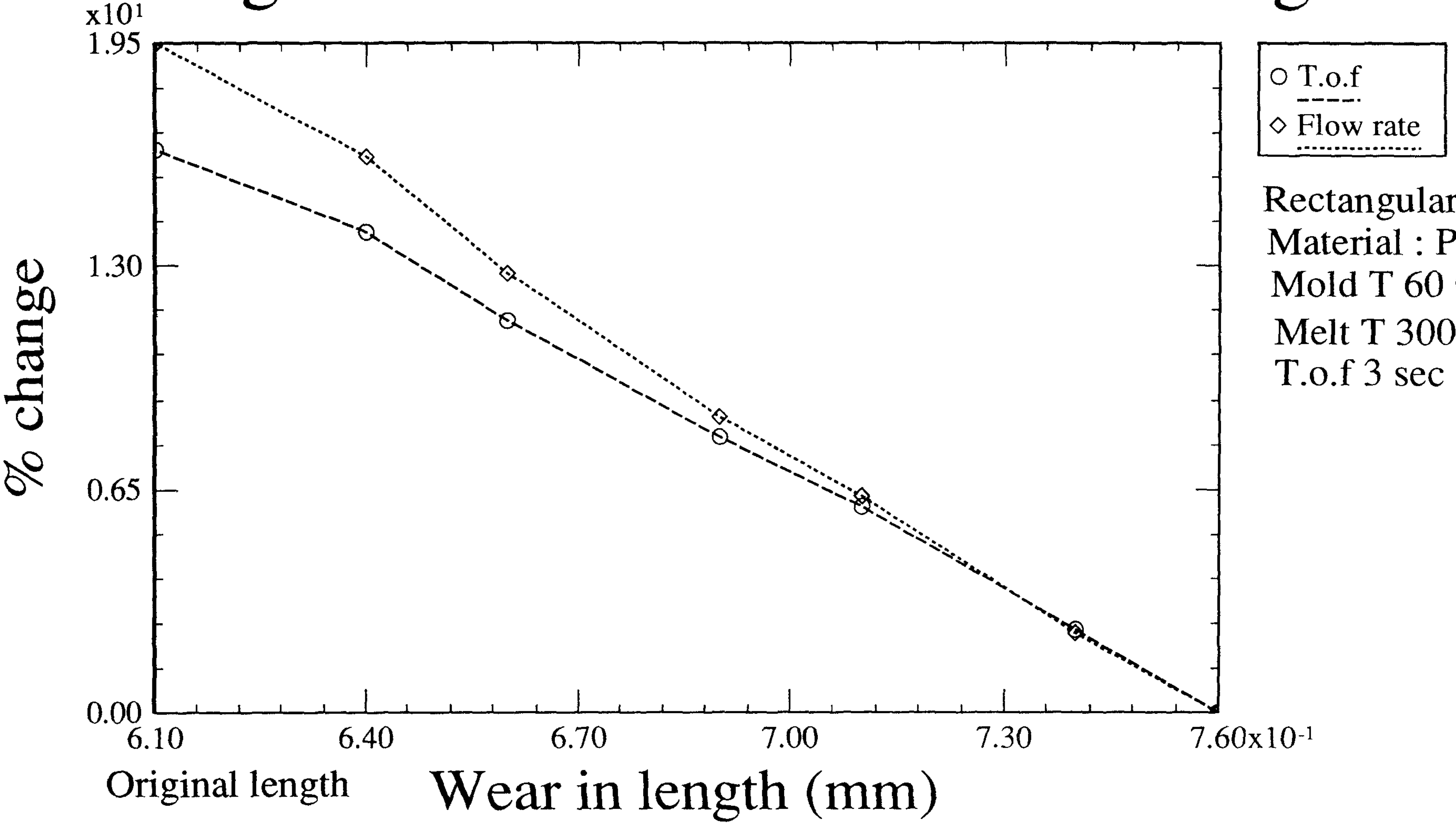
Rectangular gate

Material : PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.80

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 10 29·51 1991 (data file was /usr/tmp/TG AAAa21827)

% change in T.o.f & F.r for wear in length



Rectangular gate
Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.81

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 11 01 20 1991 (data file was /usr/tmp/TG AAAa22088)

% change in T.o.f & F.r for wear in length

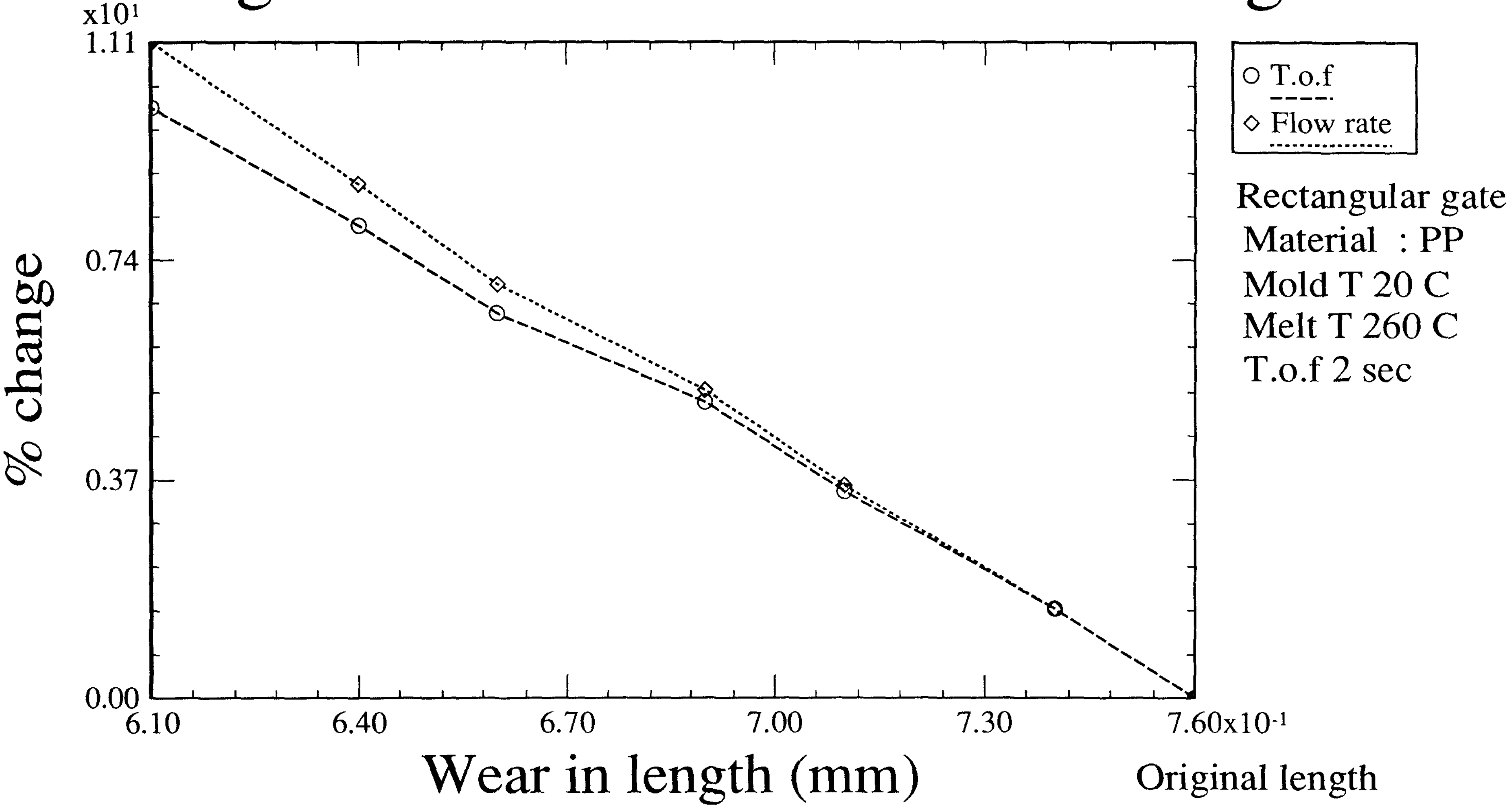


Fig. 4.82

% change in T.o.f & F.r for wear in length

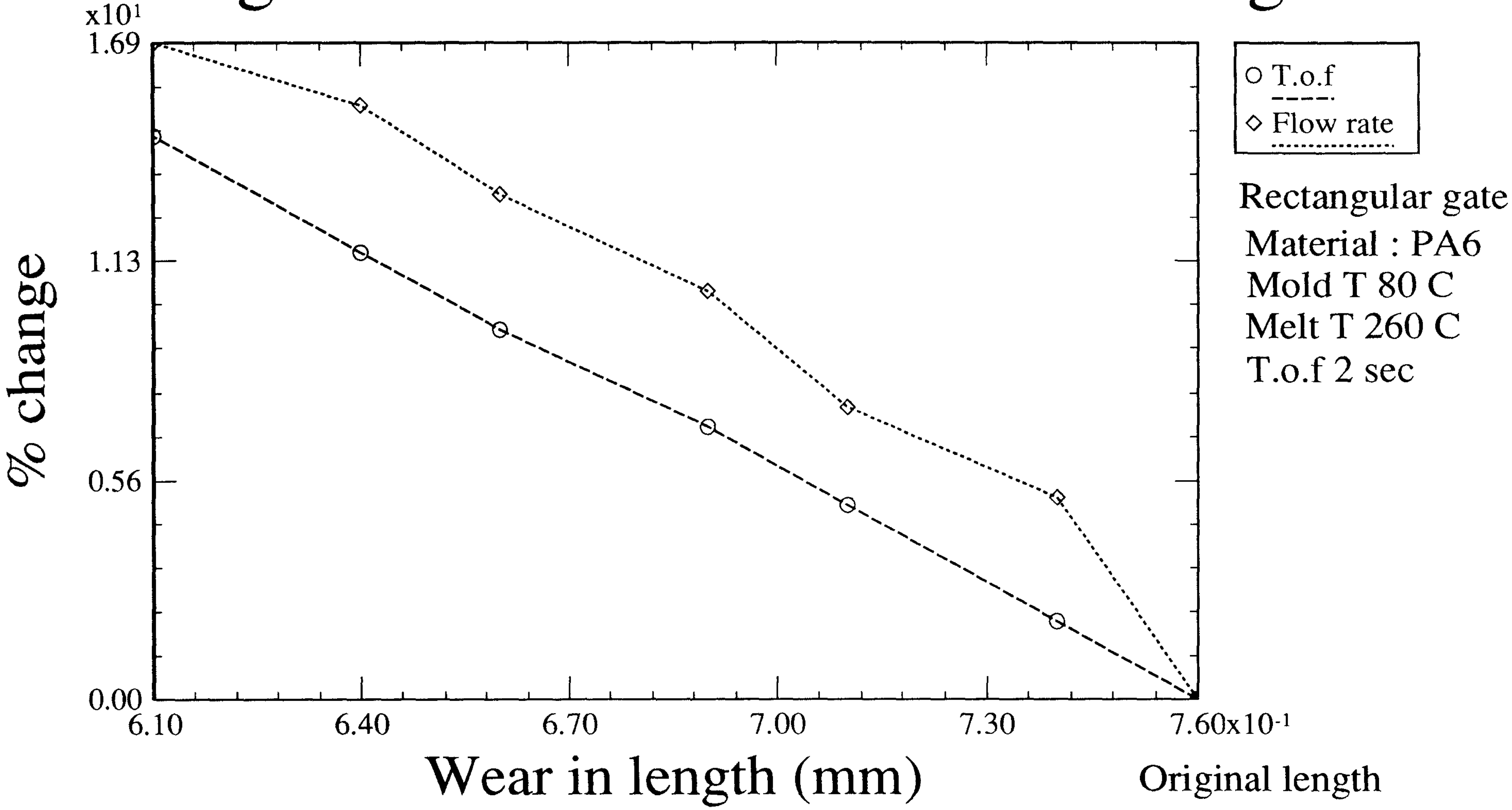
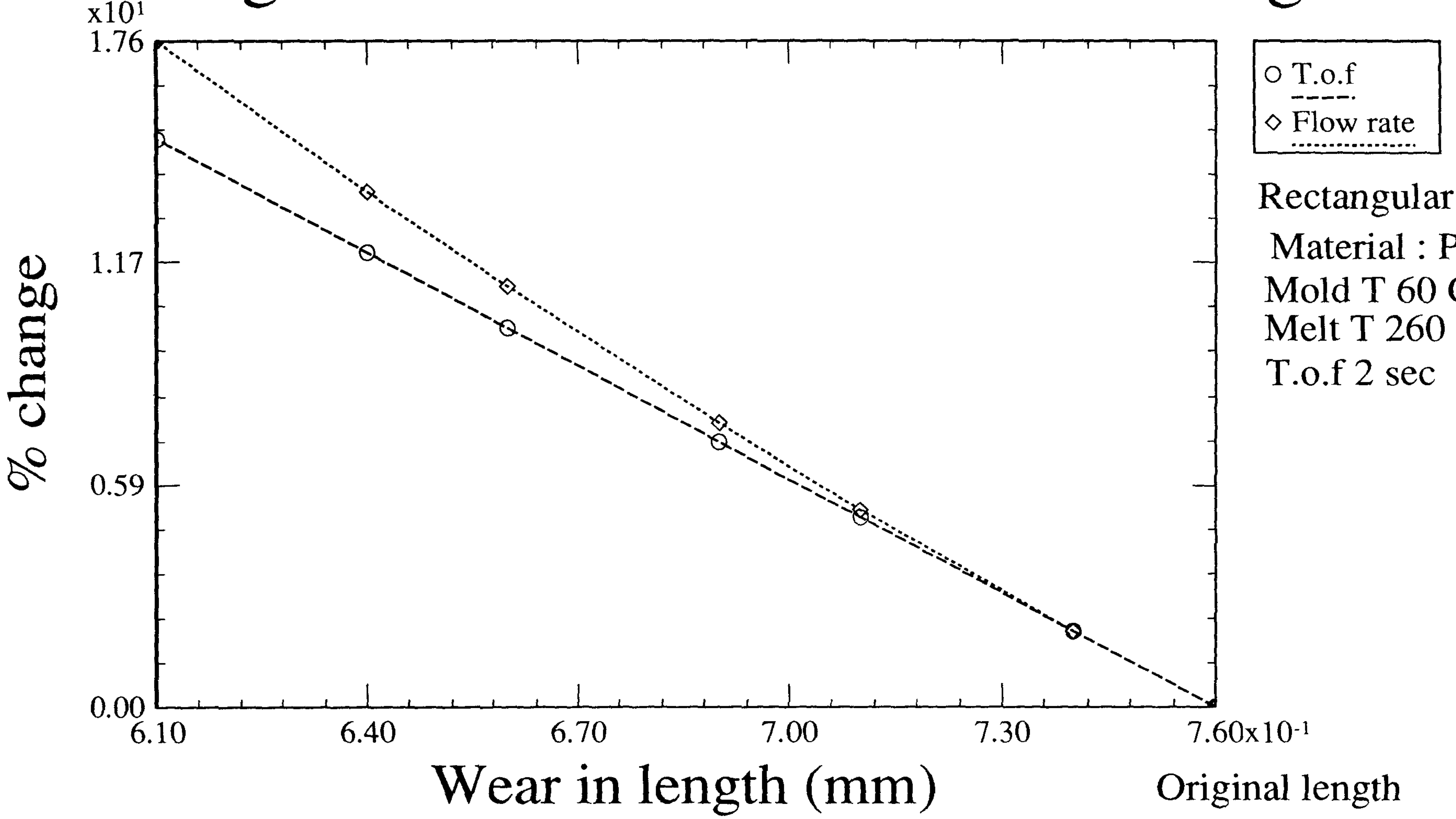


Fig. 4.83

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 11:18·09 1991 (data file was /usr/tmp/TG AAAa22088)

% change in T.o.f & F.r for wear in length

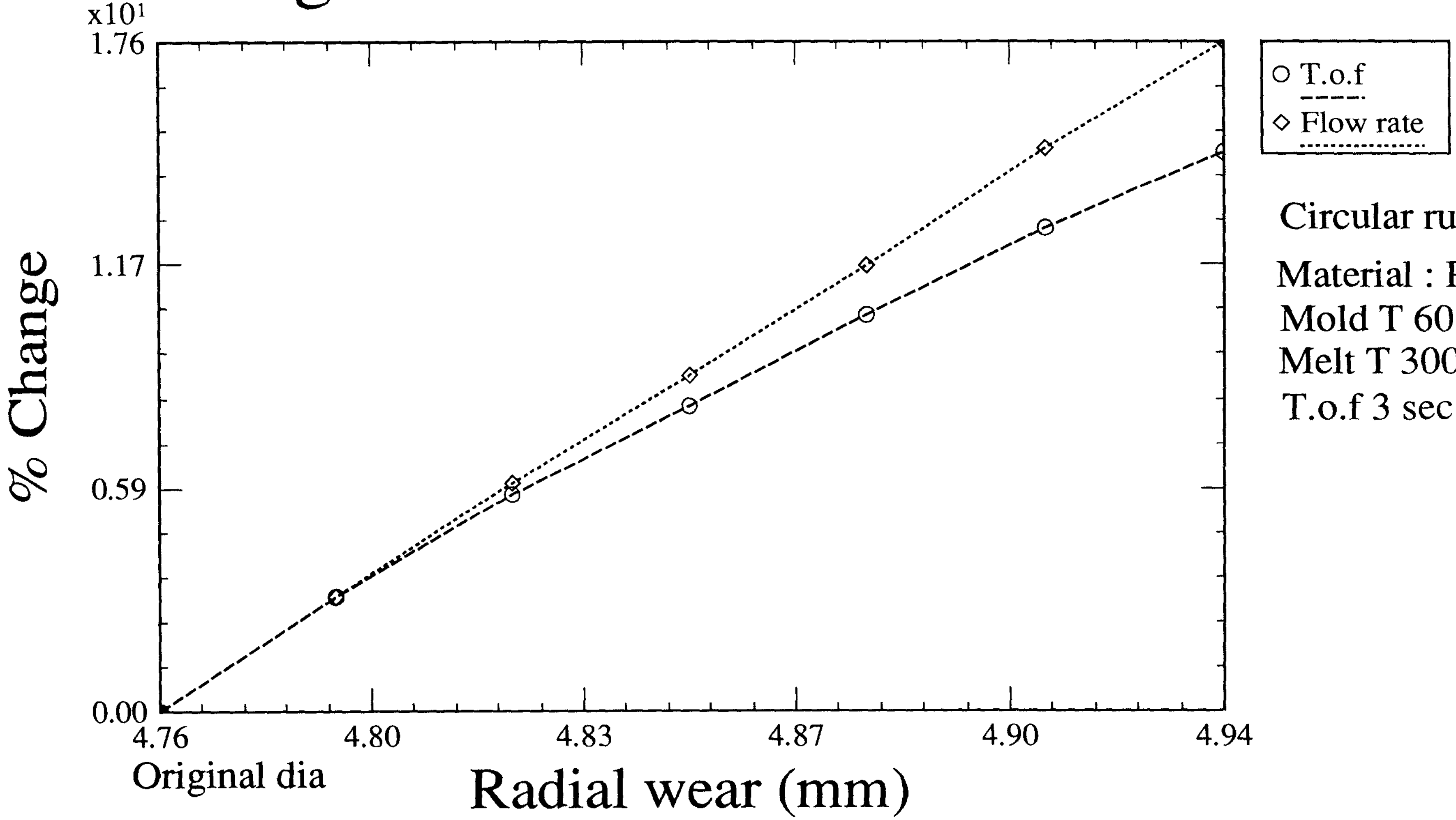


Rectangular gate
Material : PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.84

Tue May 7 11 22 23 1991 (data file was /usr/tmp/TG AAAa22088)

% change in T.o.f & F.r for radial wear



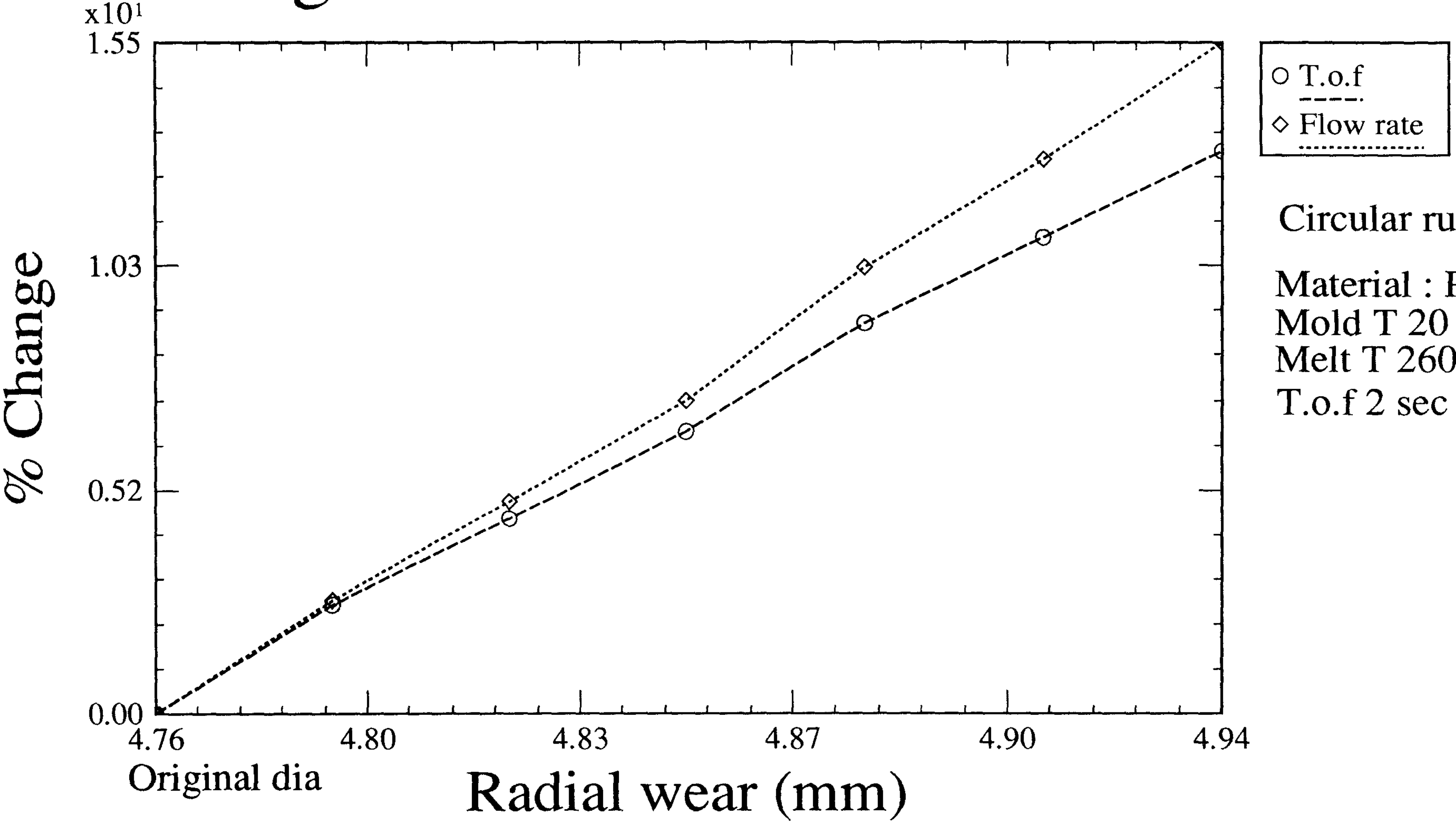
Circular runner

Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.85

/usr/mesuna/users/rva3859@mesunw4 - Mon May 6 22:20:52 1991 (data file was /usr/tmp/TG.AAAa20297)

% change in T.o.f & F.r for radial wear



Circular runner

Material : PP
Mold T 20 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.86

TempleGraph 2 3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 22:16:24 1991 (data file was /usr/tmp/TG.AAAa20297)

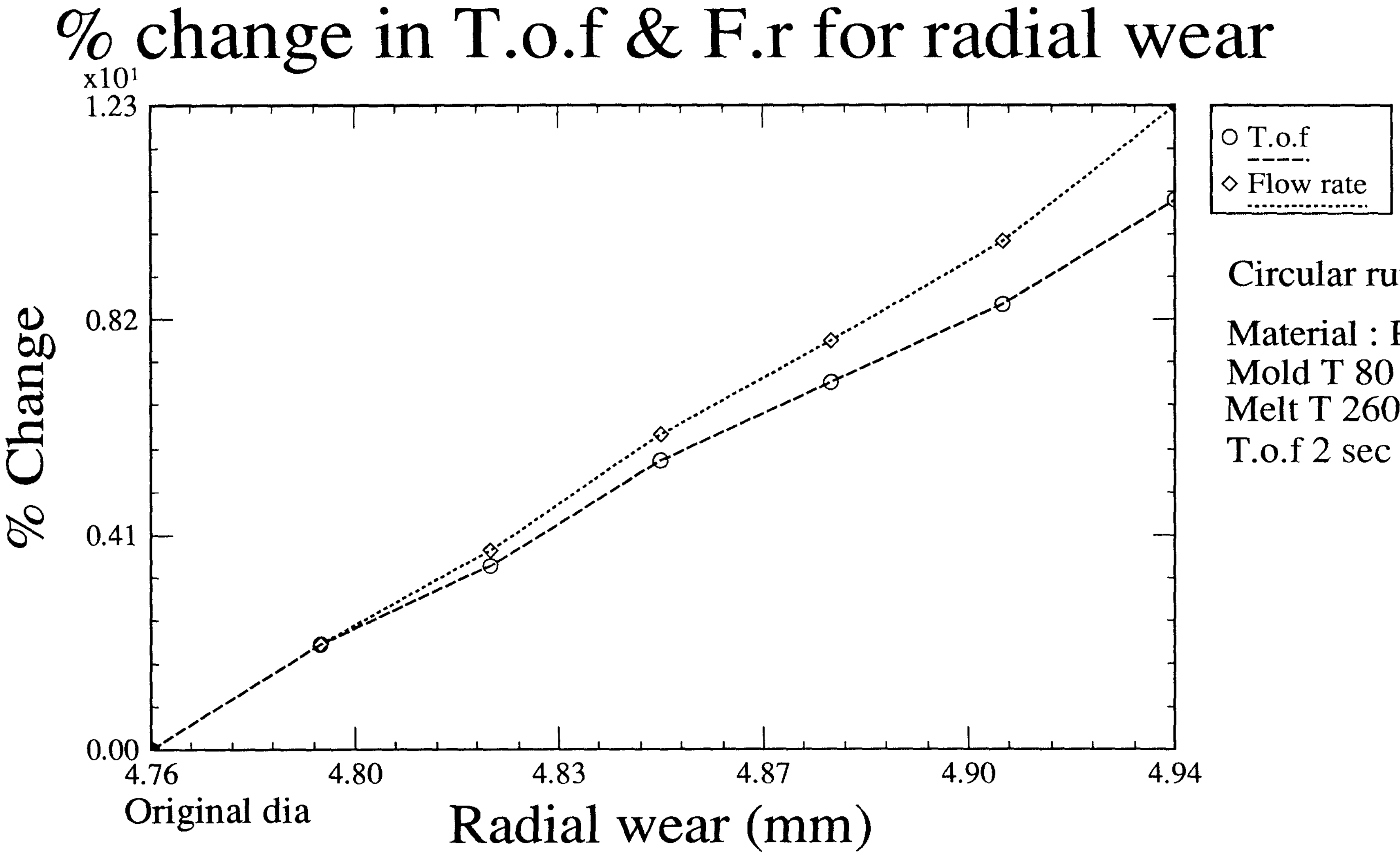


Fig. 4.87

Circular runner

Material : PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

TempleGraph 2.3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 22·11:51 1991 (data file was /usr/tmp/TG AAAa20297)

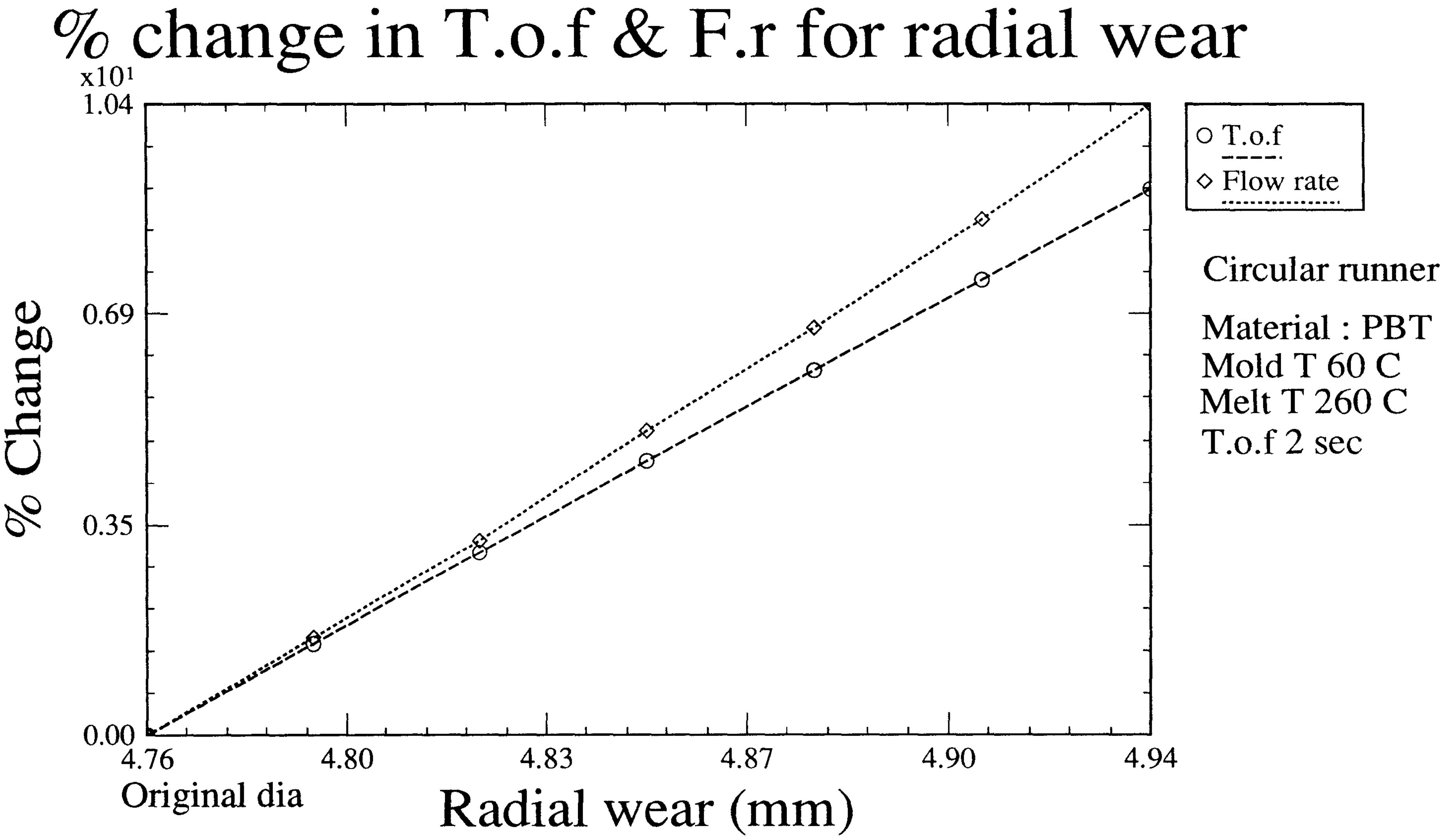


Fig. 4.88

TempleGraph 2.3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Mon May 6 22:07.31 1991 (data file was /usr/tmp/TG.AAAa20297)

% change in T.o.f & F.r for wear in width

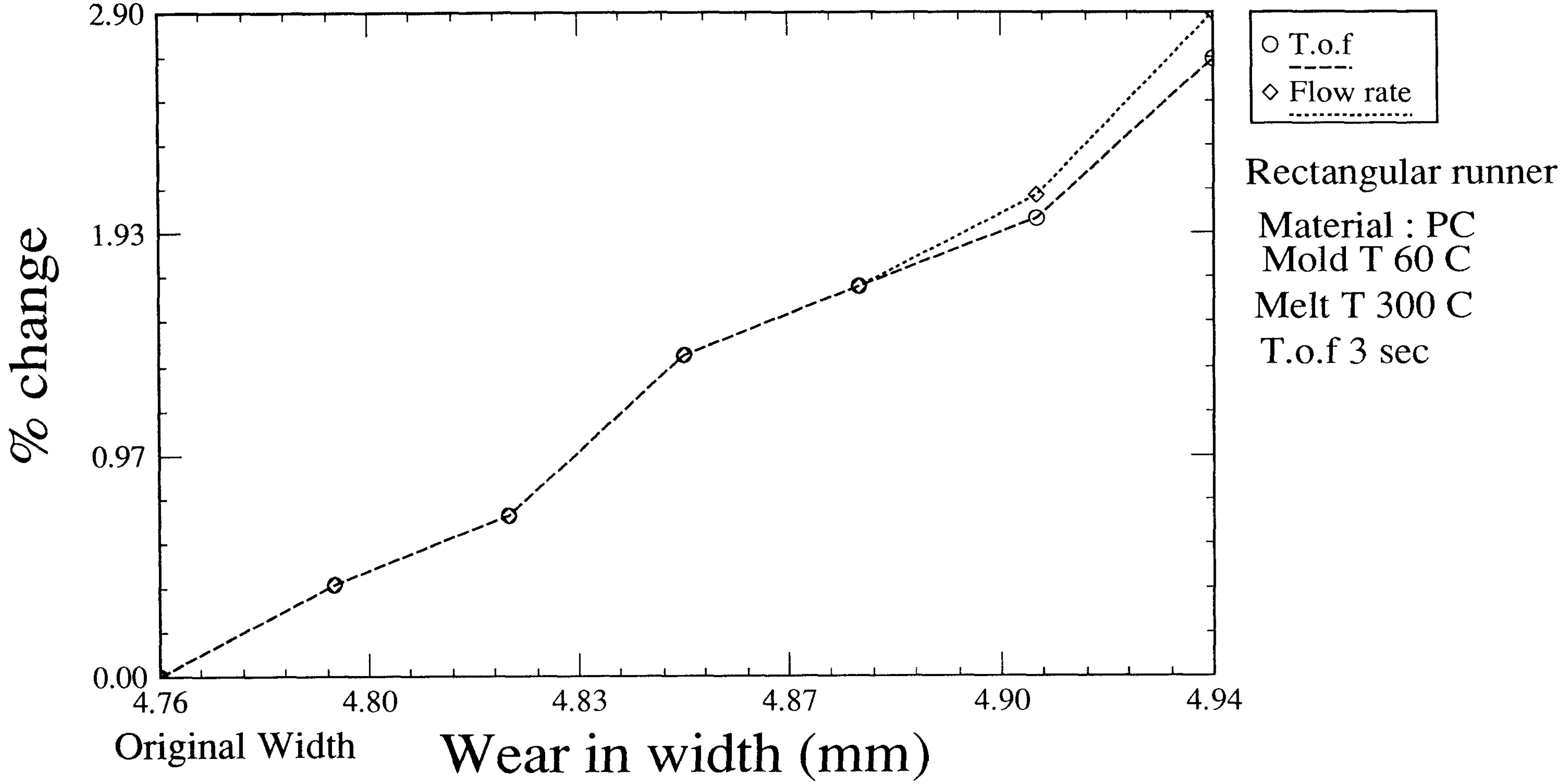
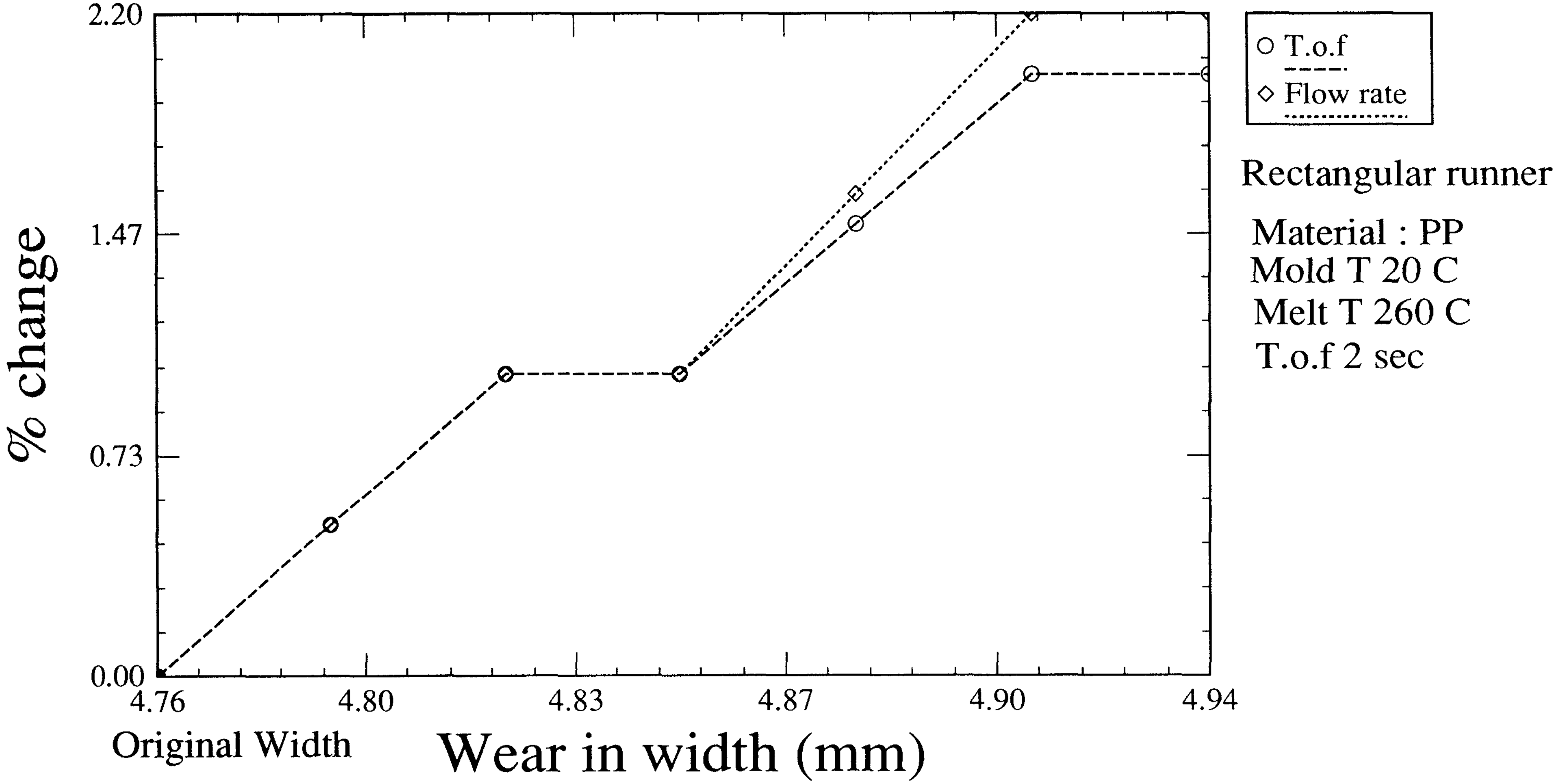


Fig. 4.89

% change in T.o.f & F.r for wear in width



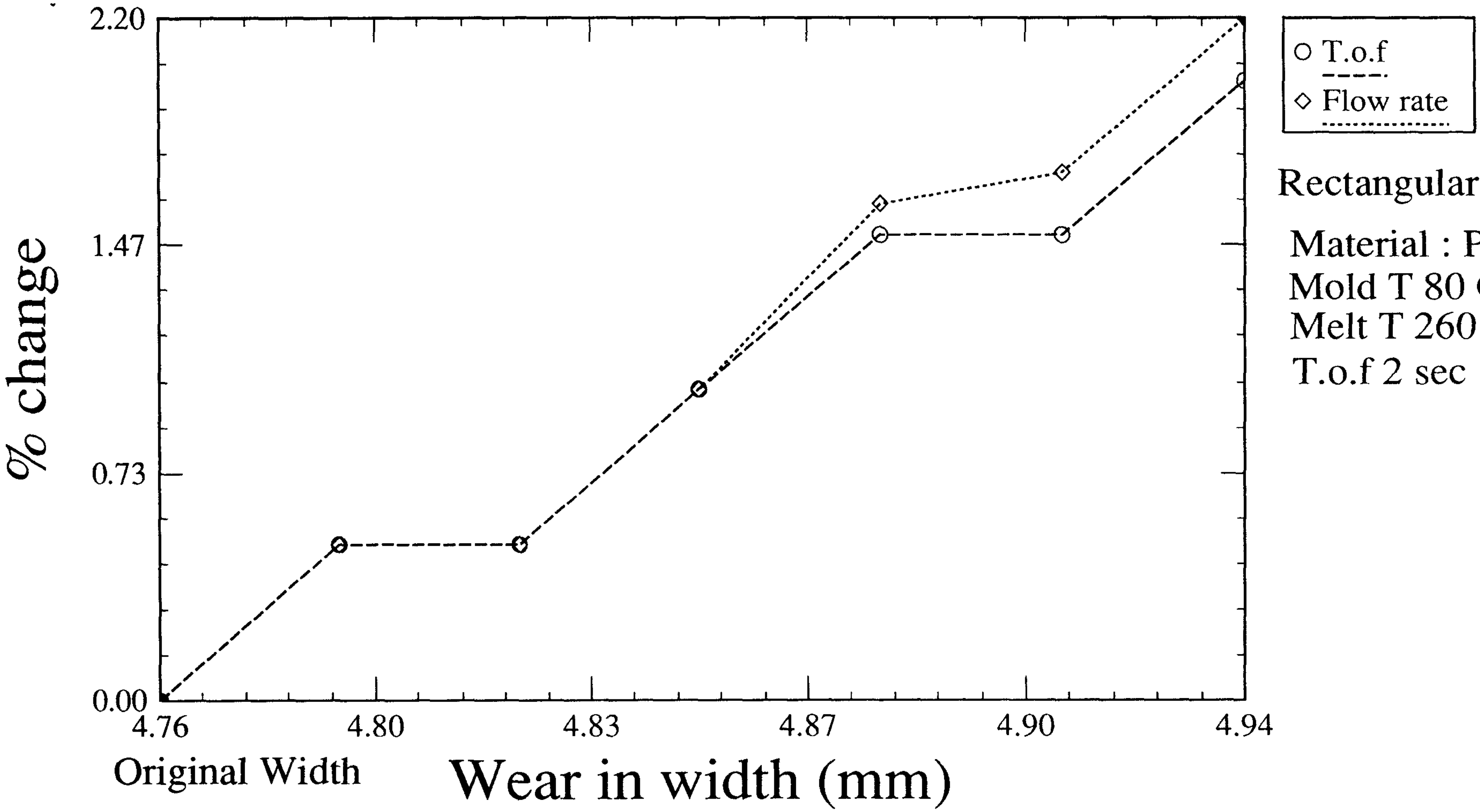
Rectangular runner

Material : PP
Mold T 20 C
Melt T 260 C
T.o.f 2 sec

Fig 4.90

TempleGraph 2.3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 11:40 17 1991 (data file was /usr/tmp/TG.AAAa22088)

% change in T.o.f & F.r for wear in width



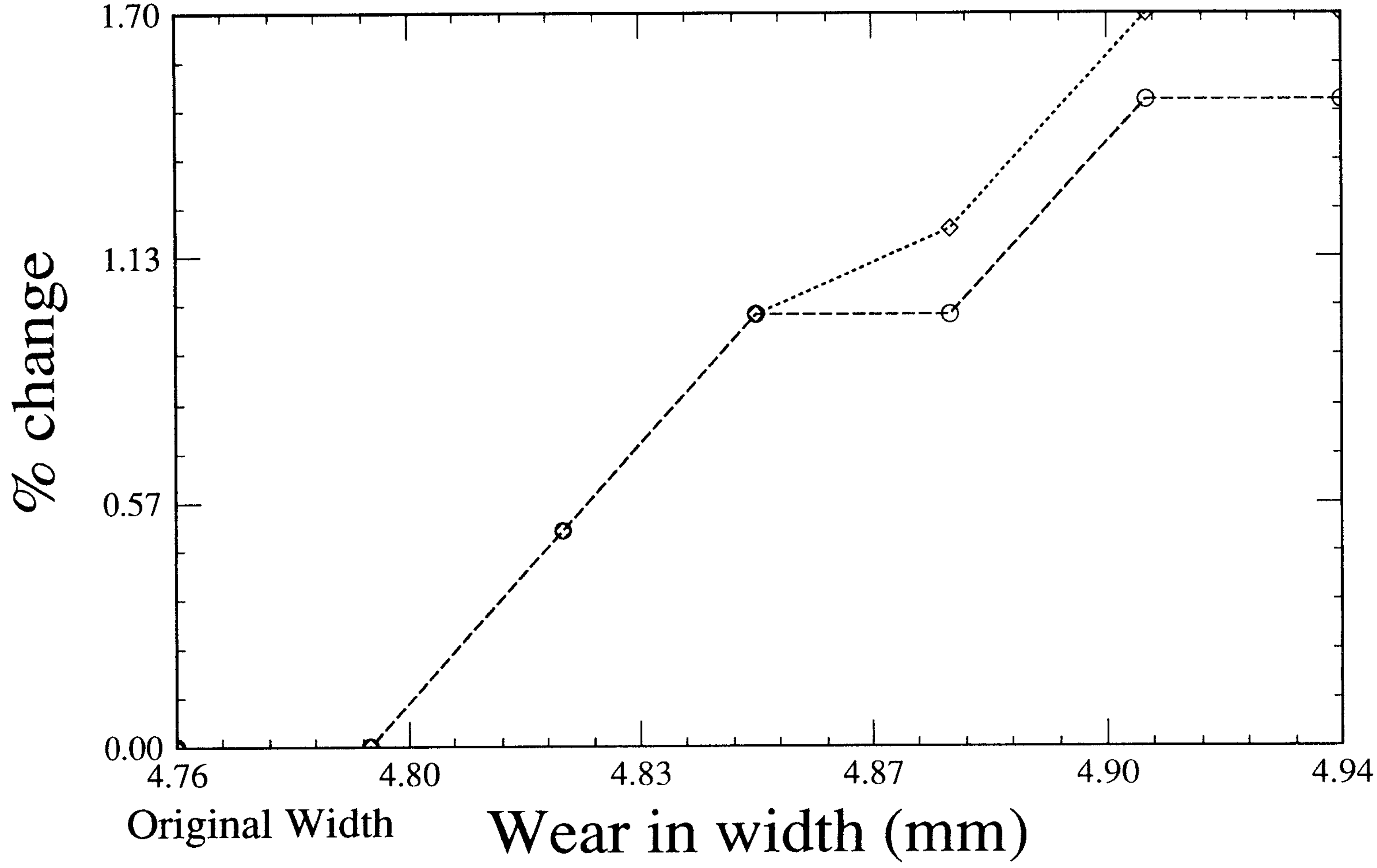
Rectangular runner

Material : PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.91

TempleGraph 2.3, Origin: /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 11.46:36 1991 (data file was /usr/tmp/TG AAAa22088)

% change in T.o.f & F.r for wear in width



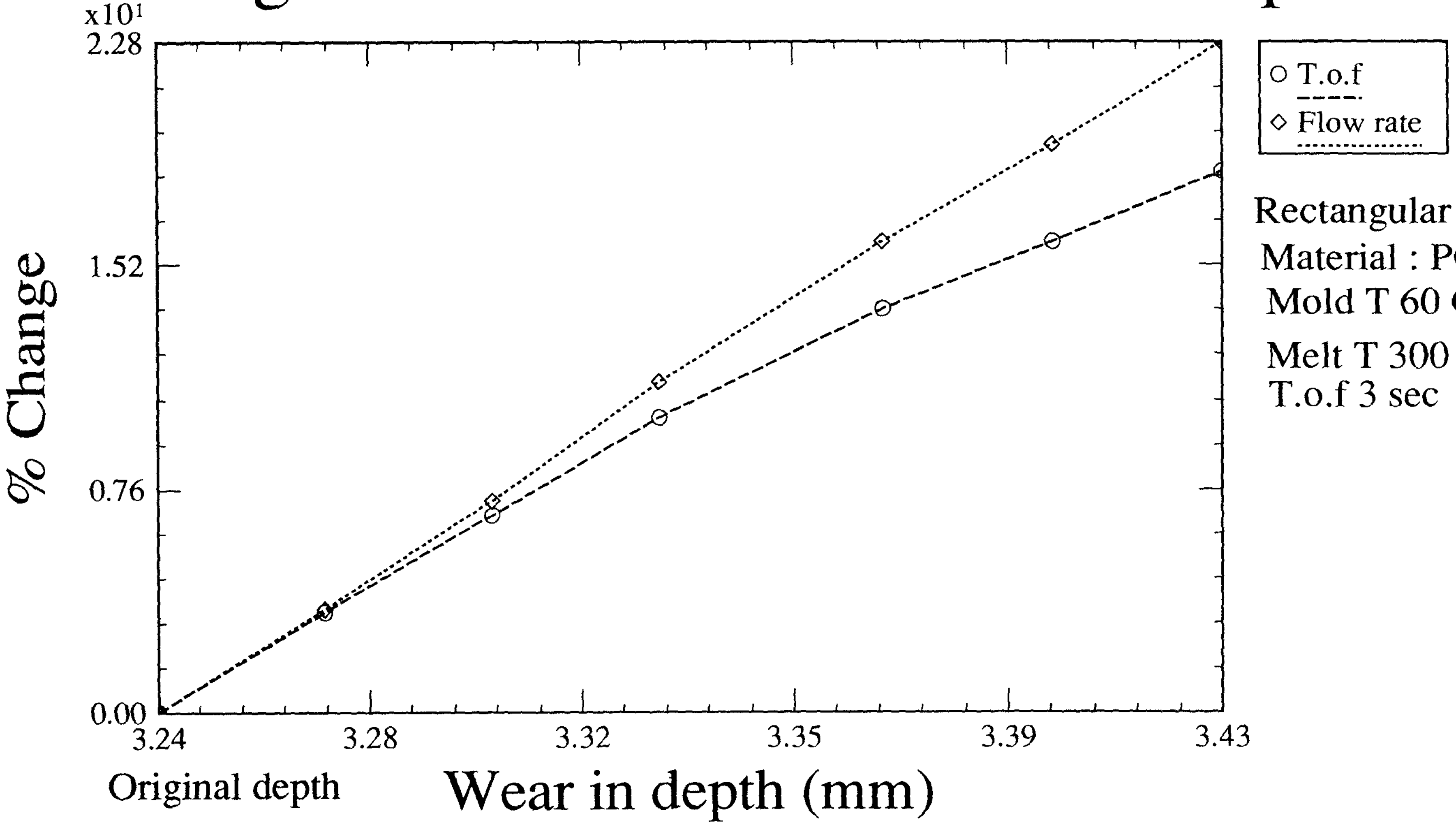
Rectangular runner

Material : PBT
Mold T 60 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.92

TempleGraph 2 3, Origin· /usr/mesuna/users/rva3859@mesunw4 - Tue May 7 11 51 37 1991 (data file was /usr/tmp/TG AAAa22088)

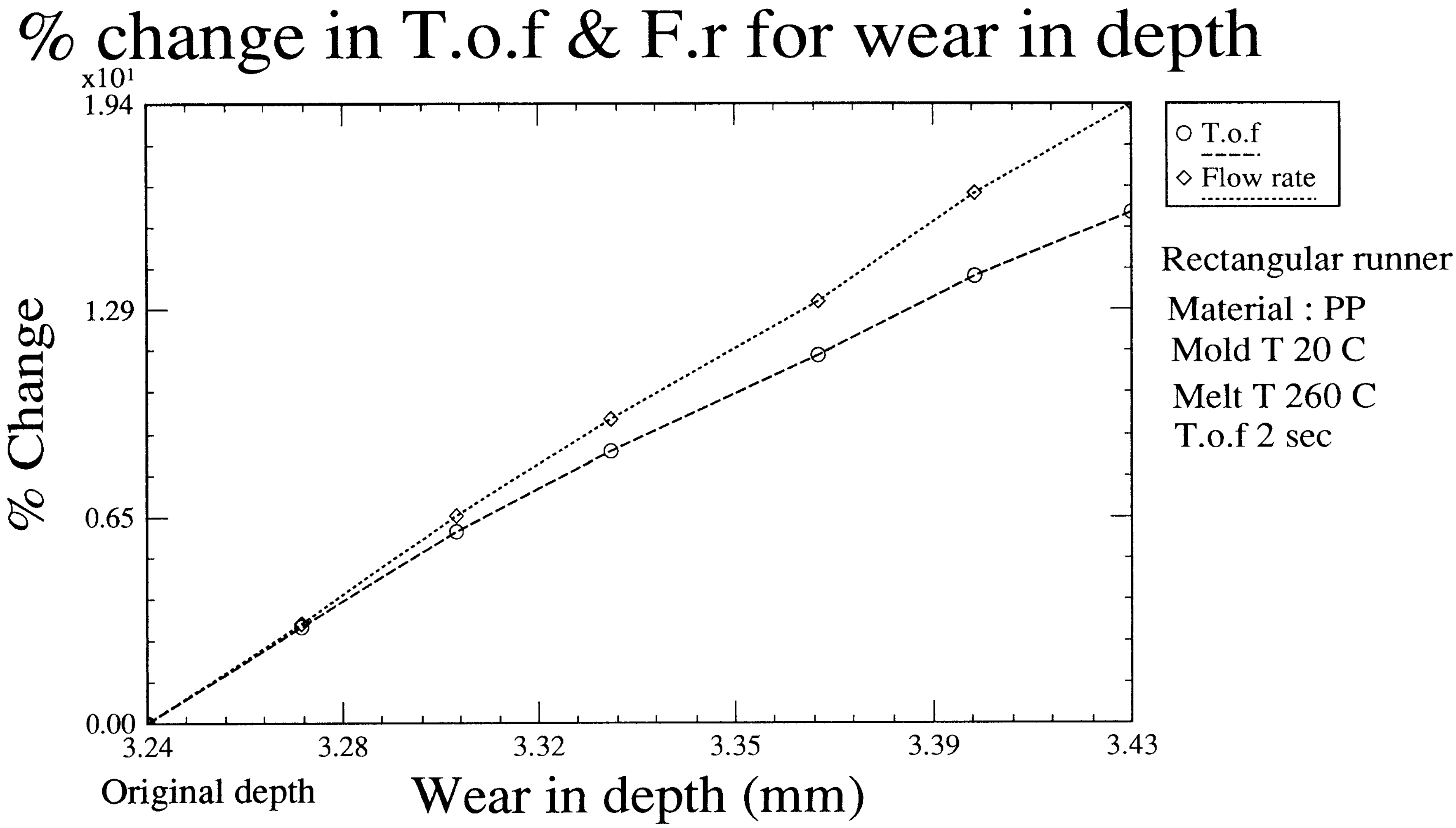
% change in T.o.f & F.r for wear in depth



Rectangular runner
Material : PC
Mold T 60 C
Melt T 300 C
T.o.f 3 sec

Fig. 4.93

[illegible]student/sn68001@mesunw4 - Tue May 7 12:15.47 1991 (data file was /usr/tmp/TG AAAa22347)



% change in T.o.f & F.r for wear in depth

Rectangular runner

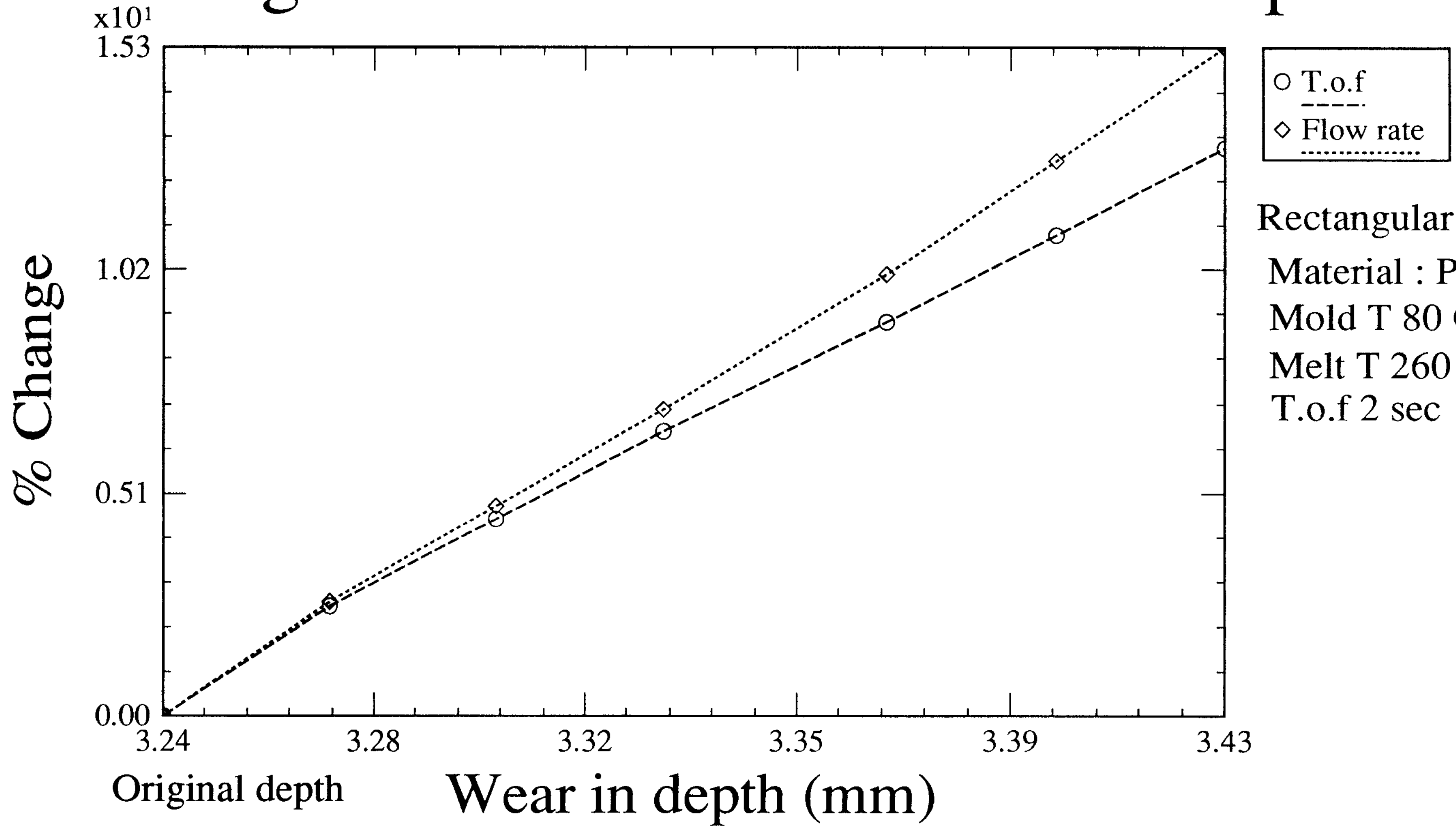
Material : PP

Mold T 20 C

Melt T 260 C

T.o.f 2 sec

Fig. 4.94



% change in T.o.f & F.r for wear in depth

Rectangular runner

Material : PA6
Mold T 80 C
Melt T 260 C
T.o.f 2 sec

Fig. 4.95

TempleGraph 2.3, Origin: /usr/student/sn68001@mesunw4 - Tue May 7 12:32 34 1991 (data file was /usr/tmp/TG.AAAa22347)

% change in T.o.f & F.r for wear in depth

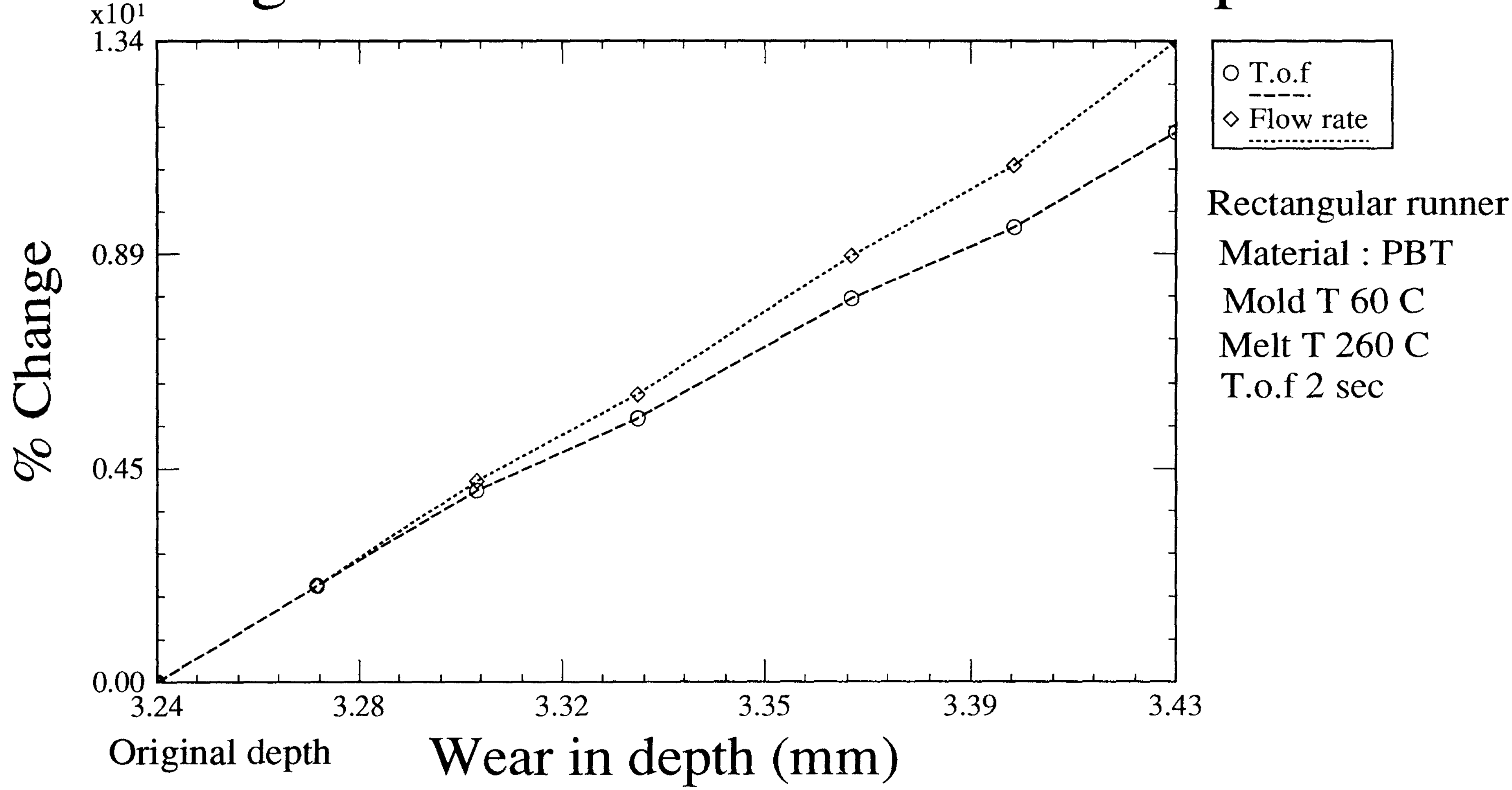


Fig. 4.96

TempleGraph 2.3, Origin: /usr/student/sn68001@mesunw4 - Tue May 7 12:37:22 1991 (data file was /usr/tmp/TG AAAa22347)