Effects of Coating Materials on Fluidity and Temperature Loss of Molten Metals from Runner Systems in Full Moulds.

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Abstract

The full mould casting process in one of the newly developed techniques which has many advantages.

Unbonded sand mould has been prepared for the major mould and CO^2 gas mould has been used occasionally for comparison.

Patterns were built up with expanded polystyrene and coated with three different materials.

Silica, graphite and zircon were used for the coating layer.

The effects on fluidity and temperature loss of molten metals were investigated.

The molten metals were Al-5% Si alloy, Cu-30% Zn alloy and gray iron of approximately 4.0% of carbon equivalent.

Experimental variables were runner section area, superheat, sprue height, coating materials, coating thickness and apparent density of EPS pattern.

The effects of coating materials on fluidity and temperature loss of the molten metals during transient pouring are summarized as follows :

As runner section area, superheat and sprue height increased, fluidity increased.

Temperature loss decreased as runner section area and sprue height increased.

However, reversed effects were observed in the case of superheat increment.

The coating materials decreased the fluidity of each alloy in the order of silica, graphite and zircon.

Zircon brought to the highest temperature loss among the coating materials used.

The fluidity increased in the order gray iron, Cu-30% Zn and Al-5% Si alloy while temperature loss in the reverse order.

Especially in case of reduced pressure process, the fluidity was increased apparently.

Al−5% Si alloy showed the lowest temperature loss among the alloys.

The increment of the apparent density of EPS pattern resulted in the fluidity decrease and temperature loss increase.

The relation between fluidity and temperature loss of each alloy can be expressed by the following equation within the coating thickness limit of 0.5−1.5 mm.

$$F^* = \frac{a}{T^* - b} - c$$

where, F^* : fluidity in the full mould.

T^* : temperature loss in the mould.

a : parameter for full mould.

b, c : constants.

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Résumé

Au cours des essais avecde fonte grise, Al—5% Si et Cu—30% Zn, dans le moule plein, les effects des matériaux de couche sur la fluidité et la perte de température de métaux fondus ont été etudiés.

La fluidité a été augmentée a mesure que la section de canal, le surchauffage et la hauteur de la descente de coulée s'augmentent. La perte de température a été diminuée selon l'augmentation de la section du canal et de la hauteur de la descente. Mais le surchauffage fait la perte de température S'élever. Les matériaux de couche abaissent la fluidité des métaux fondus dans l'ordre de la silice, le graphite et la zircon. La perte de température a été la plus grande dans le cas de la couche de zircon.

La grandeur de la fluidité augmente dans l'ordre fonte Cu—30% Zn et Al—5% Si mais celle de la perte de la température dans l'ordre inverse. Dans le cas du procédé à pression réduite l'augmentation de la fluidité a été remarquable.

La décroissance de la fluidité et l'augmentation de la perte de température ont été d'autant plus grandes que la densité apparante du modèle en EPS a été élevée.

La relation entre la fluidité et la perte de température des alliages étudiés a pu s'exprimer, dans les limites de 0.5—1.5 mm de l'épaisseur de couche, comme suivant :

$$F^* = \frac{a}{T^* - b} - c$$

où F^* : fluidité dans le moule plein;
T^* : perte de température dans le moule plein;
a : paramétre pour le moule plein;
b, c : constantes.

Zusammenfassung

Das VollformgieBverfahren ist eine neuest entwickelte GieBereitechnik, die viele Vorteile für Realisierung hat.

Es wurden binderlose Sandgiessformen hergestellt, und wasserglasgebundene, mit CO_2 gehärtete Formen zu einigen Vergleichen der Versuchswerte benutzt.

Die aus dem expandierten Polysyrol bestehenden Modelle sind mit drei verschiedenen Materialien geschichtet. Es wurden als Schlichtenmateralien Quarzmehl, Graphit und Zirkon benutzt.

Die Auswirkungen auf FlieBvermögen und Temperaturverlust der Metallschmelzen von Al—5% Si, Cu—30% Zn Legierungen und grauem GuBeisen mit etwa 4.0 Kohlenstoffäquivalent wurden untersucht. Die Untersuchung wurde in Abhängigkeit vom Querschnitt des GieBlaufs, vom Überhitzungsgrad der Metallschmelze, von der Höhe des EinguBkanales, von den Schlichtematerialien, von der Dicke der Schichteschicht und von der Dicke der Schlichteschicht und von der Dichte des expandierten Polystyrols durchgeführt.

Die Versuchsergebnisse über die Auswirkungen auf FlieBvermögen und Temparaturverlust der Metallschmelzen in kürzester GieBzeit sind kurz gefaBt folgende :

Der Temperaturverlust wird kleiner, wenn die GieBlaufquerschnittfläche und die Höhe des EingieBkanales gröBer werden, es wurde aber der gegenteilige EinfluB beobachtet, wenn der Überhitzungsgrad der Metallschmelze zunimmt.

Die Schlichtematerialien verringern in der Reihenfolge Quarzmehl, Graphit und Zirkon das FlieBvermögen der jeweiligen Legierungsschmelze.

Das FlieBvermögen wird in der Reihenfolge graues GuBeisen, Cu—30% Zn—und Al—5% Si Legierung

gröBer, wogegen der Temperaturverlust umgekehrt verläuft. Das FlieBvermögen wird besonders stark vergröBert, wenn Unterdruck angelegt wird.

Die Al−5% Si Legierung zeigte den Kleinsten Temparaturverlust. Das FlieBvermögen wurde kleiner, und der Temparaturverlust wurde gröBer, wenn die Wanddicke des expandierten Polystyrols gröBer wurde.

Die Beziehung zwischen des FlieBvermögens und Temperaturverlust der einzelnen Legierungen kann bei der Schlichtedicke von 0.5−1.5 mm mit der folgenden Gleichung dargestellt werden :

$$F^{*}=\frac{a}{T^{*}-b}-c$$

Die Bezeichnungen bedeuten :

F^{*} : FlieBvermögen in der VollgieBform; T^{*} : Temperaturverlust in der VollgieBform; a : Faktor der VollgieBform; b, c : Konstanten.

Introduction

In the full mould process which is in popular demand, selection of coating materials and thickness of coating are important for the sound casting process.

Since Shroyer(1) applied for a patent in 1958, papers in Japan and elsewhere were reported on the study of cast alloys in full mould(2-3) and the temperature loss inside the runner in cavity sand mould(4-5) was examined.

They investigated the effects of fluidity and temperature loss separately.

However, nearly no attempt was made to exploit the properties of coating materials which generated evaporation of polystyrene and resistance by gas pressure.

In the full mould process, the amount of generated gas is much different depending on the pouring temperature.

The fluidity and temperature loss also depend on coating materials as well as its thinkness.

In this paper the effect of runner cross section area (hereinafter referred to as "runner section area"), super heat, sprue height, coating thickness, and apparent density of EPS pattern were studied.

Silica, graphite and zircon were chosen for the coating materials.

Three molten alloys namely, Al−5% Si alloy, Cu−30% Zn alloy and gray iron were used in these studies.

The relation between fluidity and temperature loss was pursued and correlated through casting theories.

2. Experimental Procedure

2-1. Pattern and mould

A foamed polystyrene plate was used for the runner patterns for straight fluidity test.

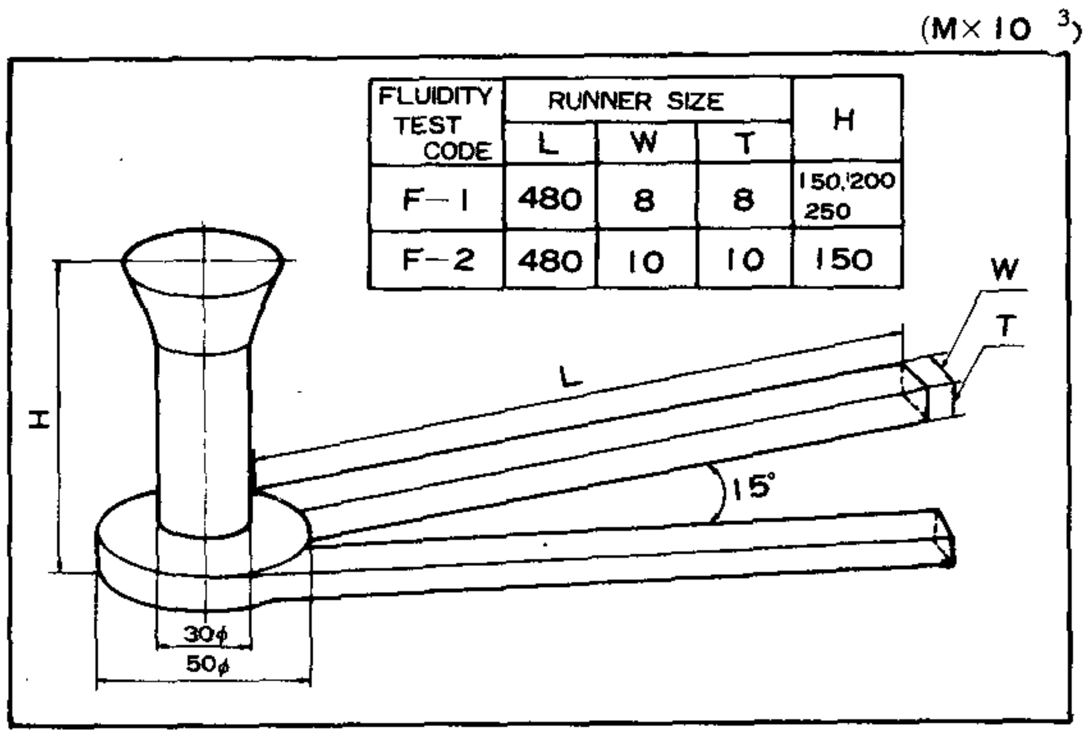
Two runner patterns were fabricated.

Approximate runner section areas of 8×8 mm and 10×10 mm each and both length of 480 mm were cut.

The sprue, made of the same material as runner, had a circular shaped cross section area of 30 mm in diameter.

Fig. 1 shows two runners attached radially to the sprue base of 50 mm in diameter and 20 mm in depth.

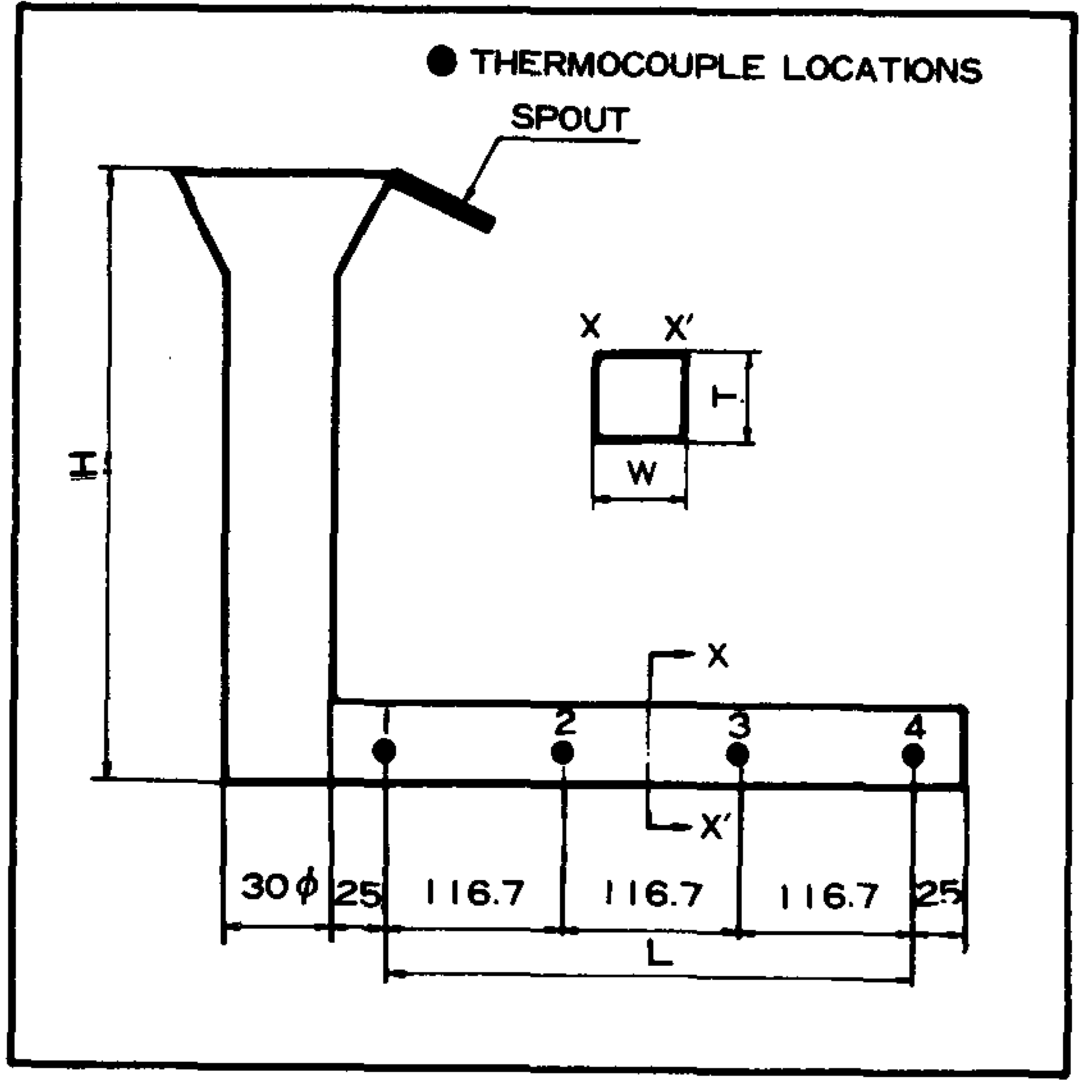
Fig.1 Fluidity test casting and dimensional details.



FLUIDITY TEST CODE	RUNNER SIZE			H
	L	W	T	
F−1	480	8	8	150,200 250
F−2	480	10	10	150

As shown in Fig. 2, a runner of 14×14 mm and 16×16 mm and 350 mm in length was connected to the same sprue in order to measure temperature loss.

(M× 10 ^{3})



(M× 10 ^{3})

RUNNER TYPE CODE	RUNNER SIZE			H
	L	W	T	
R−1	350.1	14	14	150
R−2	350.1	16	16	150, 200 250

Fig. 2 Temperature lose test casting and thermocouple locations.

Coating materials used for the pattern are given in Table 1. The grain sizes of zircon flour, silica flour, and graphite powder(referred to as "zircon, silica, and graphite") were in the range of 270−325 mesh.

A gating pattern(hereinafter referred to as "pattern") was dipped into a mixture of coating materials and then dried in an oven at the temperature of 50−60℃ for about 5 hours.

The mixtures were prepared by mixing a little amount of adhesive, methyl alcohol, and coating materials in order to prevent coating layer from being broken.

Thicknesses of dried coating were 0.5 mm, 1mm and 1.5 mm respectively with an accuracy of ± 0.1 mm.

A mould box was made using a 3 mm thick steel plate.

The dimension of the box was 200×600×250 mm.

Many holes of 2 mm in diameter were drilled in order to vent the gas generated during the pattern was evaporated.

For a reduced pressure test, the mould box were divided into two regions by placing a steel plate with many holes horizontally.

The bottom part of the mould box was connected to the vacuum pressure box.

A manometer was attached on the vacuum pressure box for monitoring reduced pressure.

The CO_2 gas mould was made by mixing a sodium silicate with silica sand(AFS GFN=65).

Table 1. Chemical composition of coating materials

Alloy	Camposition (wt. %)								
	C	Si	Mn	P	S	Cu	Zn	Al	Fe
Gray iron	3.3-3.5	1.6-2.0	0.5-0.7	0.05-0.07	0.1-0.2	−	−	−	bal.
Cu−30% Zn	−	−	−	−	−	bal.	28.7-31.9	−	−
Al−5% Si	−	4.6-5.2	−	−	−	−	−	bal.	−

Most unbonded sand moulds were made of the same silica sand as the CO_2 gas mould.

Apparent density of 1.5 g/cm^3 was achieved by vibrating the mould.

A plastic film was covered on the top of the mould in case of reduced pressure test. Just before pouring, a pressure of approximately −200kPa was measured at the vacuum pressure box.

2-2. Melting

For melting an Al−5% Si alloy, pure aluminium ingot and Al−30% Si alloy were charged in the clay graphite crucible.

A siliconit electric furnace was used for melting the alloy.

Cu−30% Zn was also melted by charging pure copper and pure zinc ingot in the same furnace.

Melting the gray iron was carried out in the high frequency induction furnace.

Charging materials were foundry pig iron, ferro-silicon and electrode scrap.

The C.E. value of approximately 4.0 was controlled by monitoring the C.E. meter.

Chemical composition of the alloys are given in Table 2. In order to maintain constant sprue height, the pouring cup (made of CO_2 gas mould) placed on top of the sprue allowed the overflowing during continuous pouring.

The top the mould except the pouring cup was covered with an asbestos plate with many holes.

A weight was applied in order to prevent the mould from being broken due to buoyancy of molten metal and pressure of generated gas. Pouring temperatures of each alloy were 25℃, 50℃, and 75℃ above the liquidus at the location 1, respectively.

2-3. Measurement

Fluidity length (hereinafter referred to as fluidity), as shown in Fig. 1, denoted the average length of the two runners from the joint of sprue base to the location which the molten metal reached in the runner.

As shown in Fig. 2, CA and PR thermocouples were placed at the location 1, 2, 3, and 4.

The thermocouple was inserted through a thin walled pyrex or a quartz tube of 1 mm inner diameter.

For the measurement of temperature of the location, the square root ratio of total volume of gating system to the runner volume up to each location was calculated.

If the pouring time for total volume of the gating system could be measured, the time for melt reaching to each designated region could be calculated.

Temperature difference of each location could be finally determined by the temperature−time curve, which was printed out from the automatic temperature measurement system.

Each thermocouple was read every second.

The temperature difference between location 1 and location 4 was taken as temperature loss since temperature differences at location 2 and 3 was

Table 2. Chemical compositions of casting alloys used.

Materials	Composition (wt. %)					
	SiO_2	Al_2O_3	Fe_2O_3	ZrO_2	TiO_2	C
Silica flour	98.76	0.21	0.23	−	−	−
Zircon flour	33.21	0.13	0.08	66.24	0.25	−
Graphite powder	−	−	−	−	−	98.10

insignficant to those of location 1.

3. Results and Discussion

3-1. Effect of runner section area

Fig.3 shows the variation of the fluidity to the runner section area of 64 and 100 mm^2 for gray iron, Cu—30% Zn alloy and Al—5% Si alloy.

The pattern was coated with 1 mm thick zircon, graphite and silica respectively.

For all cases, fluidity increases runner section area increases.

In case of silica coating to Al—5% Si alloy, a change of runner section area from 64 mm^2 to 100 mm^2 results in 37 mm difference of fluidity from 210 mm to 247 mm.

Meanwhile, the differences for the cases of Cu—30% Zn and gray iron, become shorter by approxmately 24 mm, 23 mm respectively.

The fluidity from zircon coating are the shortest and that from graphite coating are in the middle for all alloys.

Fig. 4 illustrates the change of temperature loss when the runner section areas are varied from 196 mm^2 to 256 mm^2.

As the runner section area increases, the temperature loss tends to decrease.

The highest temperature loss is approximately measured to be 52℃ from the case of gray iron, in the runner section area of 196 mm^2.

The lowest temperature loss appears to be 19℃ from the case of Al—5% Si alloy, the runner section of 256 mm^2.

This observation can be explained as follows.

As in the case of cavity sand moulds the mould ratio increases by increasing the runner section area, and cooling rate decreases according to the Chvorinov's rule.

It is believed that the tendency of the gas generated from EPS patterns to resist the metal flow gets sensitive, as the runner section area gets smaller in the full mould.

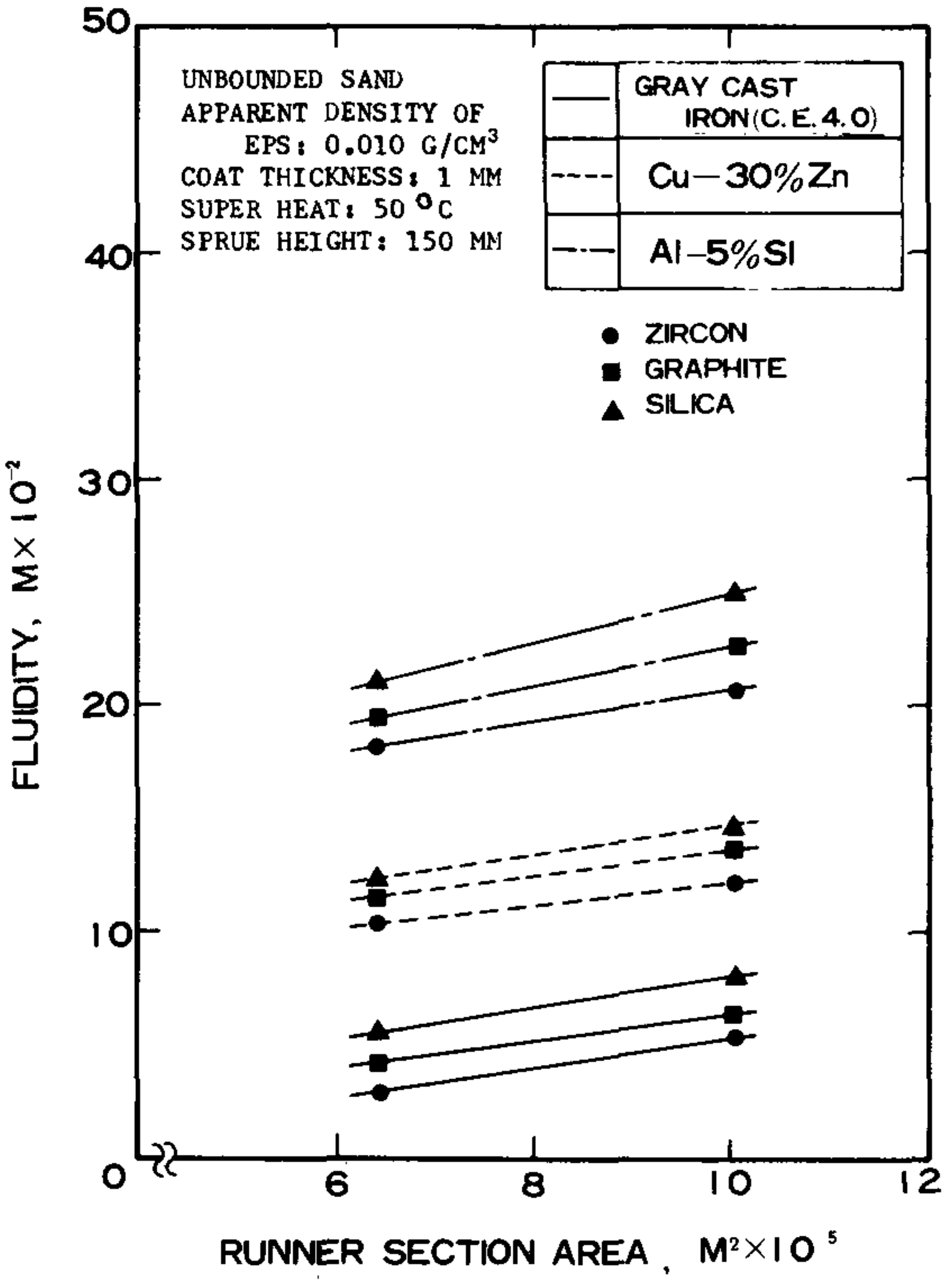


Fig. 3 Relationships between fluidity and runner section area for three casting alloys with different coating material

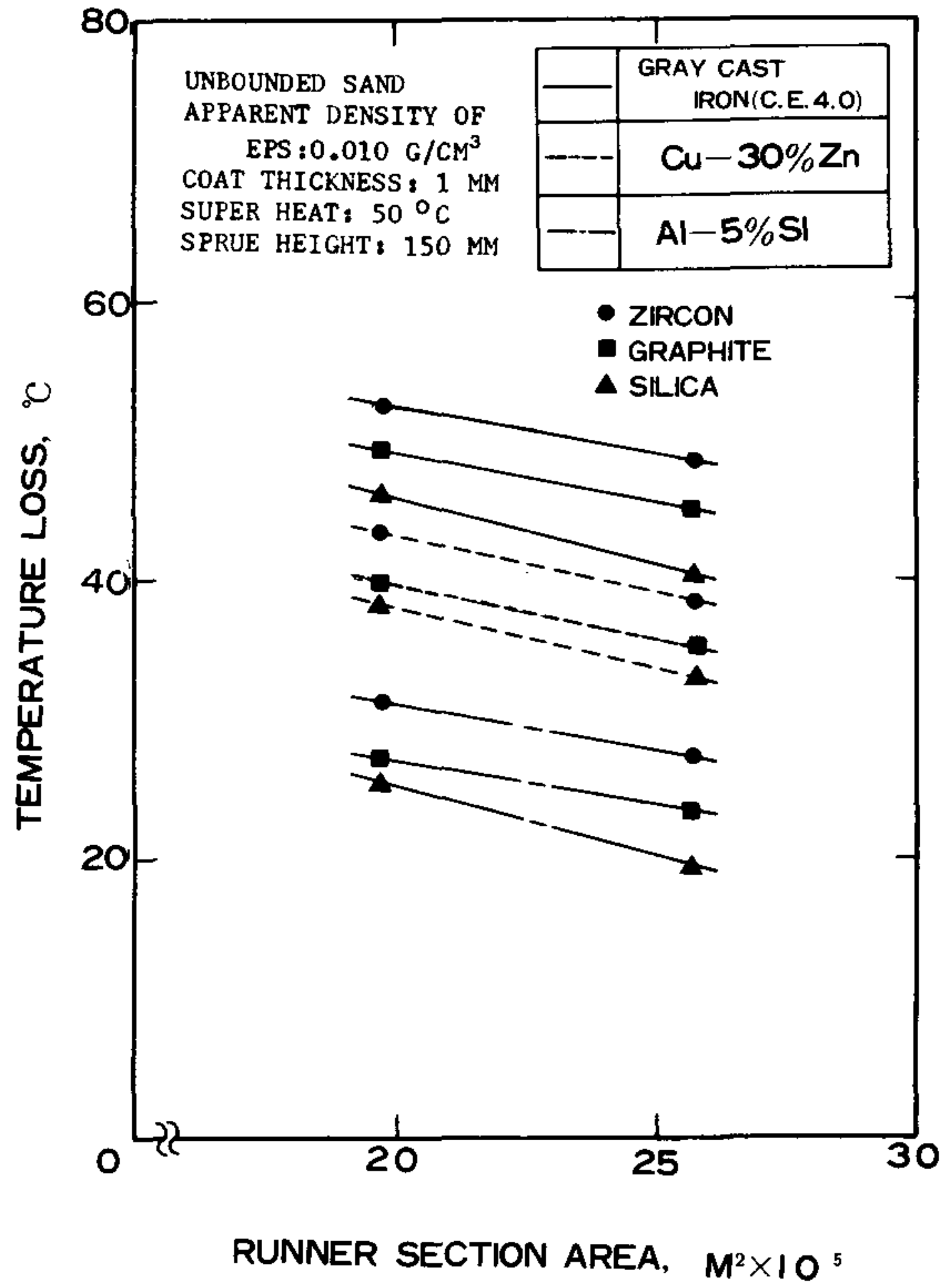


Fig. 4 Relationships between temperature loss and runner section area for three casting alloys with different coating material

Although the increment of runner section area promotes the increment of fluidity, doubled runner section area does not represent doubles fluidity as in the cavity sand mould(6) and appears much less.

In other words, it can be shown that there is a direct relationship between runner section area and fluidity or reversed relationship to temperature loss.

Thermal properties of coating materials also affects to fluidity or temperature loss in a certain runner section area.

This result is consistent with the Sakaguch et al's(3) report on fluidity investigation.

They reported that the change of runner section area with aluminium alloy resulted in an extension of pouring time in the full mould.

3-2. Effect of superheat

Fig. 5 illustrates the relationship between superheat and fluidity of alloys with different coating.Generally the fluidity increases as superheat increases. The longest length of fluidity depending on superheat is shown in Al−5% Si alloy, followed by Cu−30% Zn and gray iron in order.

It is understood that fluidity is also affected by metal flow and thermal properties of coating material under certain casting conditions, which can be expressed by the function of superheat. It is assertive that superheat is very effective for improvement of fluidity of the metal flow.

The result corresponds to the of another paper that superheat is effective to remelting the solidified metal on the runner wall.(7) The increment of fluidity from the alloy of wide solidification range was mainly due to superheat(8)

This was verified in the fluidity experiments of aluminium alloy.

The temperature loss dependence to superheat is plotted in Fig. 6. Gray iron is more sensitive

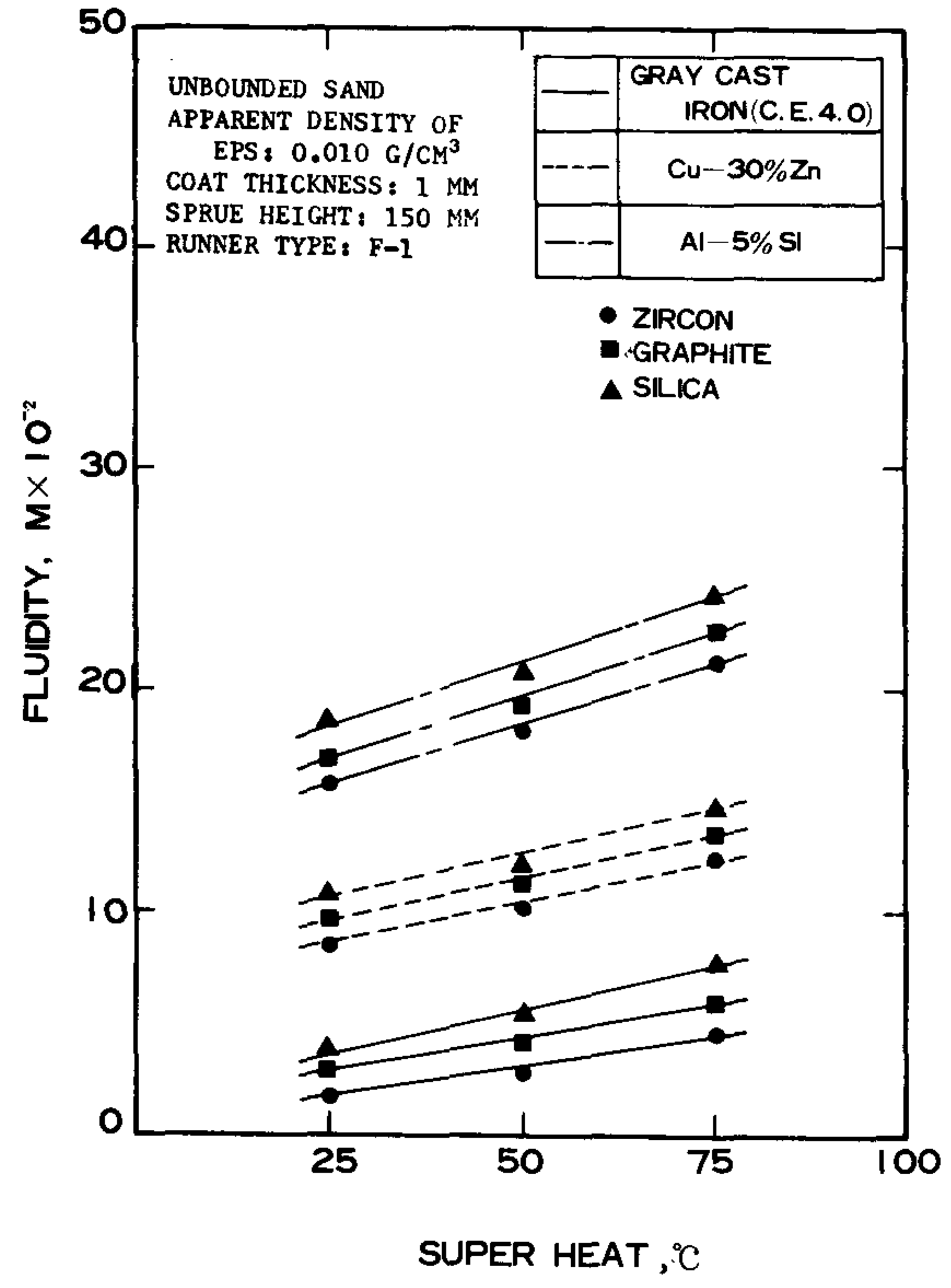


Fig 5. Relationships between fluidity and super heat above liquidus three casting alloys with different coating material

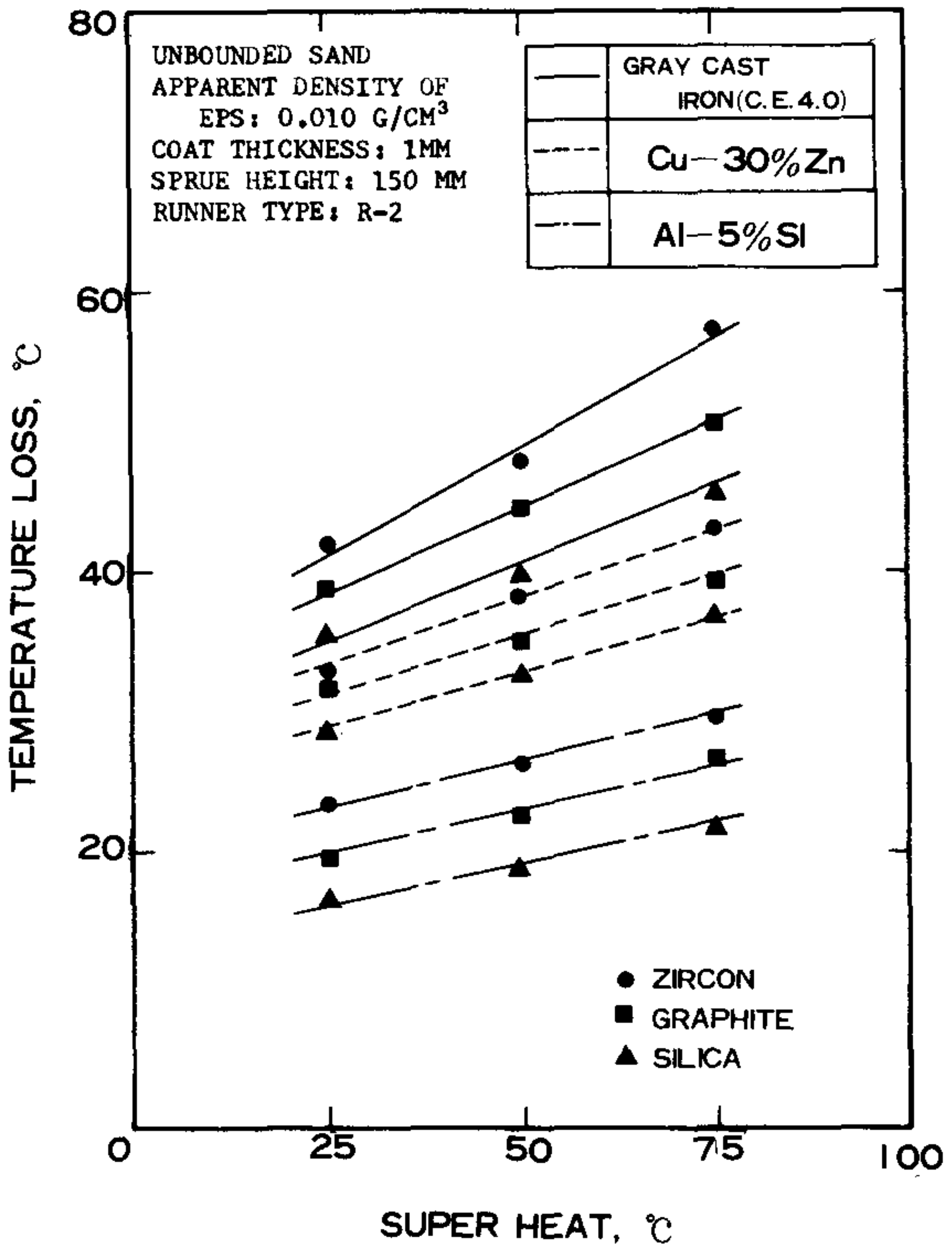


Fig 6. Relationships between temperature loss and super heat above liquidus for three casting alloys with different coating material

and has more temperature loss than Cu−30% Zn and Al−5% Si alloy according to the increment of superheat.

From the viewpoint of convection, a higher temperature generates more gas from EPS pattern and induces severer convection. This results in an increment of the heat transfer coefficient at metal−mold interface.

This is also similar to the phenomenon in which lots of gas generate when gray iron is poured.

3-3. Effect of sprue height

Fig. 7 illustrates that fluidity increases as the sprue height increases in the full mould.

Fig. 8 demonstrates that temperature loss decreases as sprue height increases.

In other words, pouring time decreases as sprue height increases.

Fluidity is influenced by coating material at a certain sprue height.

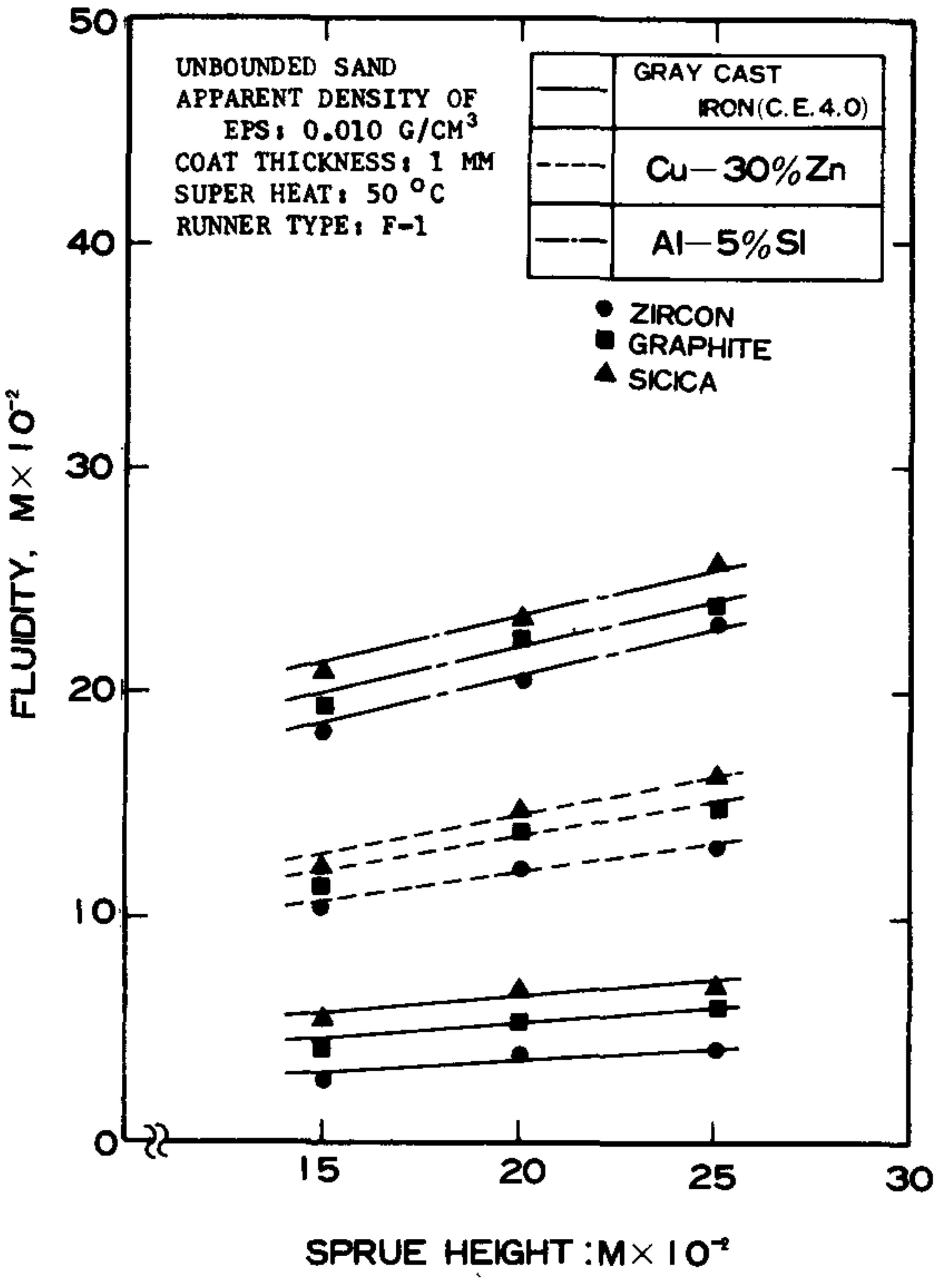


Fig.7 Relationships between fluidity and sprue height for casting alloys with different coating material.

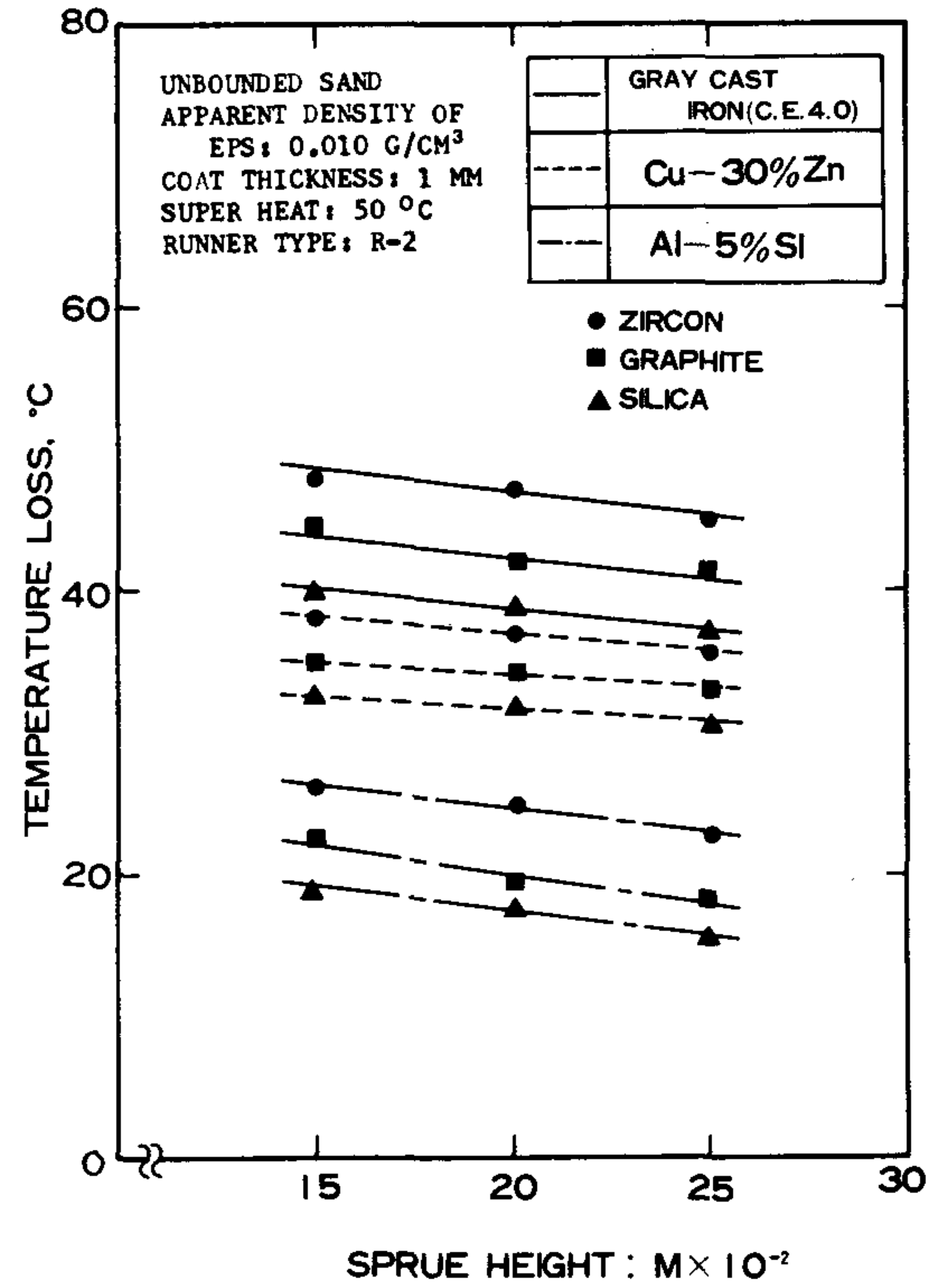


Fig. 8 Relationships between temperature loss and sprue height for three casting alloys with different coating material.

Pressure of the gas generated in the runner reduces the pouring rate and heat loss due to runner wall thickness increases pouring time and decreases fluidity.

It is believed that a decrease of pouring rate would result in some difficulties of metal flow because of gas generated from EPS pattern.

Namely, in case that sprue height is 150 mm in zircon coated gray iron, the highest temperature loss and lowest fluidity are measured.

It is understood that rapid pouring should be made in zircon coated gray iron considering the fact that the fluidity increases a slight increment in case of sprue height of 250mm.

Lee⁽⁹⁾ concluded that metal flow rate could be divided into accelerating and retarding stages, and the pouring rate should be kept faster through an investigation of pouring time of gray iron in the full mould.

3-4. Effect of coating thickness

Most EPS patterns used in the full mould casting should be coated.

Selection of coating materials and the thickness of coating are important factors for sound casting.

Changes of fluidity depending on coating material and its thickness for each alloy is illustrated in Fig. 9.

In particular, the result of zircon coating to each alloy at the reduced pressure of 200 KPa is plotted.

There is a tendency to fluidity decreaes as the thickness of coating material increase.

In case of zircon coated pattern and Al−5% Si, fluidity is 183 mm long at the 1.5 mm thick coating material while approximately 300 mm at the reduced pressure. The fluidity of gray iron and Cu−30% Zn are quite lower.

However, the differences compared to reduced pressure are relatively small in comparison with the case of Al−5% Si alloy.

Fig. 10 is a plotting of the temperature loss dependance to coating thickness.

Increases of coating thickness result in increases of temperature loss.

It is believed that fluidity and temperature loss are depended on chilling power($\sqrt{k.\rho.c}$) of the coating material, except in the case of graphite used.

This is why degree of penetration decreases as the thickness of graphite coating increases and unburned carbon generated from EPS pattern remains in the surface of coated metal flow.

It is considered to act as an insulator.

Unburned carbon is found partially in the runner casting surface after solidification.

Fluidity increases at reduced pressure condition corresponding to the other literature.

Takeuchi et al[10] applied reduced pressure for the study on solidification of a Al−4.5% Cu alloy in the full mould.

They reported that heat transfer coefficient at the metal−mould interface increases at the reduced

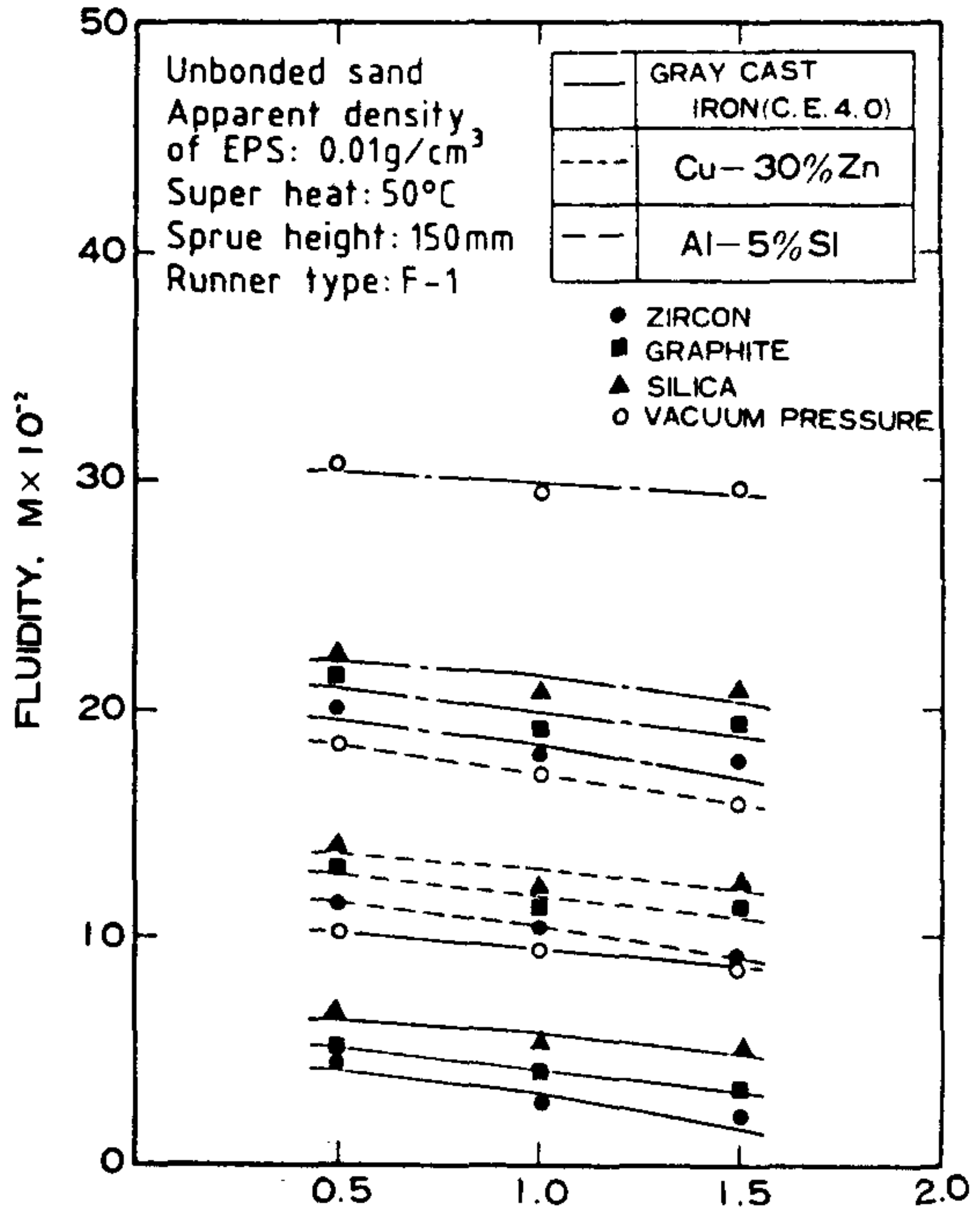


Fig. 9 Relationships between fluidity and coating thickness for three casting alloys with different coating material

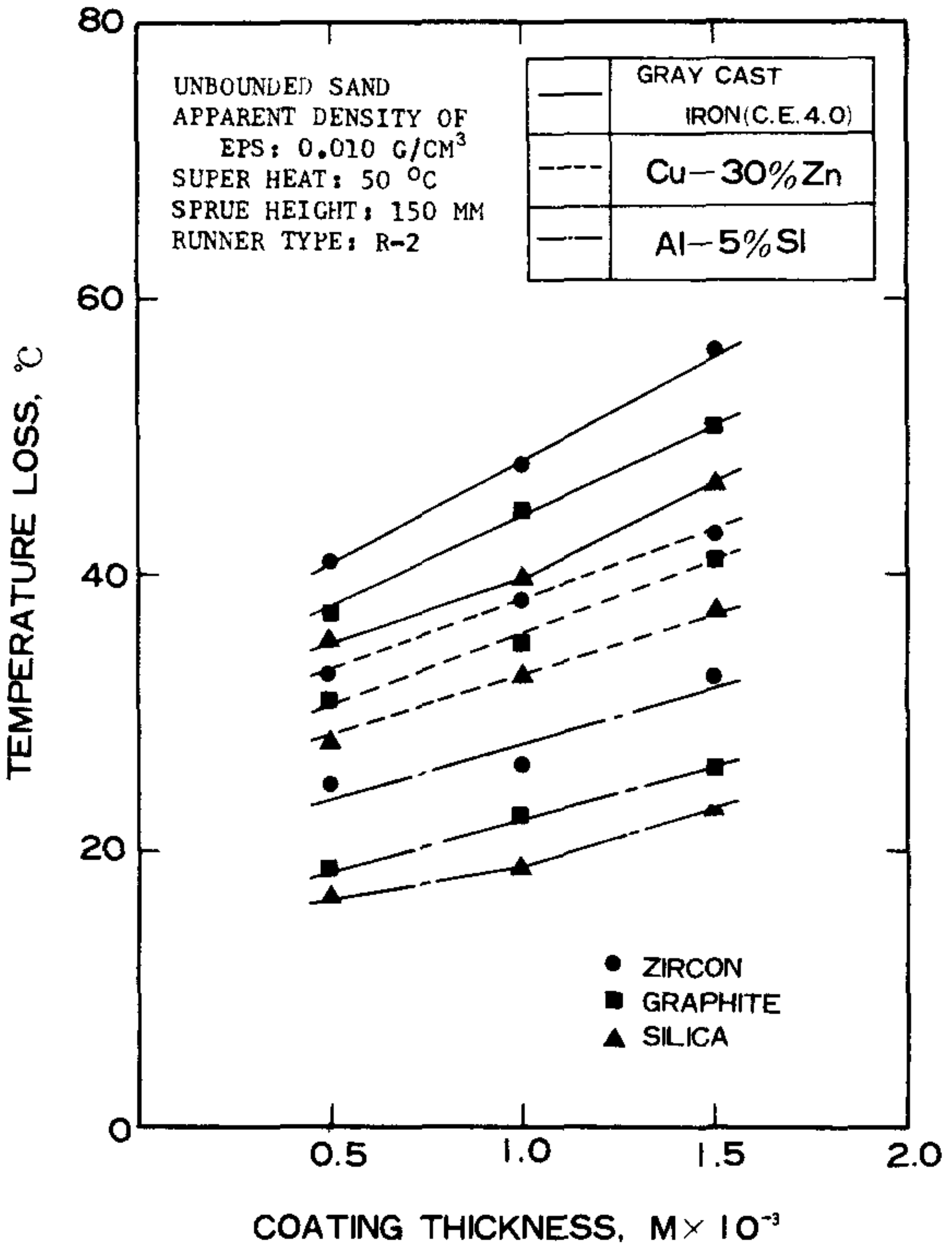


Fig. 10 Relationships between temperature loss and coating thickness for three casting alloys with different coating material

pressure in comparison with casting under atmospheric pressure.

3-5. Effect of apparent density of EPS pattern

Fig. 11 is the result of apparent density of EPS and fluidity for various alloys and coating materials. Fluidity decreases as apparent density of EPS increases.

The differences between 0.015 and 0.020 g/cm^3 are larger than those between 0.010 g/cm^3 and 0.015 g/cm^3.

It is estimated that the amount of generated gas incresaed as the apparent density increased.

Unvaporized EPS will reduce the gas permeability of the coating layer during pouring.

Therefore, the gas can not be easily vented out.

Fig. 12 illustrates apparent density of EPS and temperature loss.

An apparent density of 0.015 g/cm^3 or higher leads to higher differences in temperature loss.

On the other hand an Al−5% Si alloy in the cavity of a sodium silicate CO_2 gas mould shows a smaller temperature loss than in the unbonded sand mould.

There is a gap between metal and mould in the case of the sodium silicate/CO_2 gas mould with lower permeability.

Therefore the amount of heat transfer from metal to mould is smaller than from unbonded sand mould.

Goria et al(11) reported that the heat lost during the vaporization of EPS patterns induced temperature drop in the advancing stream of metal.

3-6. Relation between fluidity and temperature loss

Flemings(12) has derived an equation fluidity for skin forming alloys. His formula is as follows :

$$F=\frac{\rho_s \cdot a \cdot v}{2 \cdot h \cdot (Tm-To)}(H+c'\triangle T) \qquad (1)$$

where, F : fluidity (in m)

ρ_s : density of solid metal (in kg/m^3)

a : radius of runner of fluidity (in m)

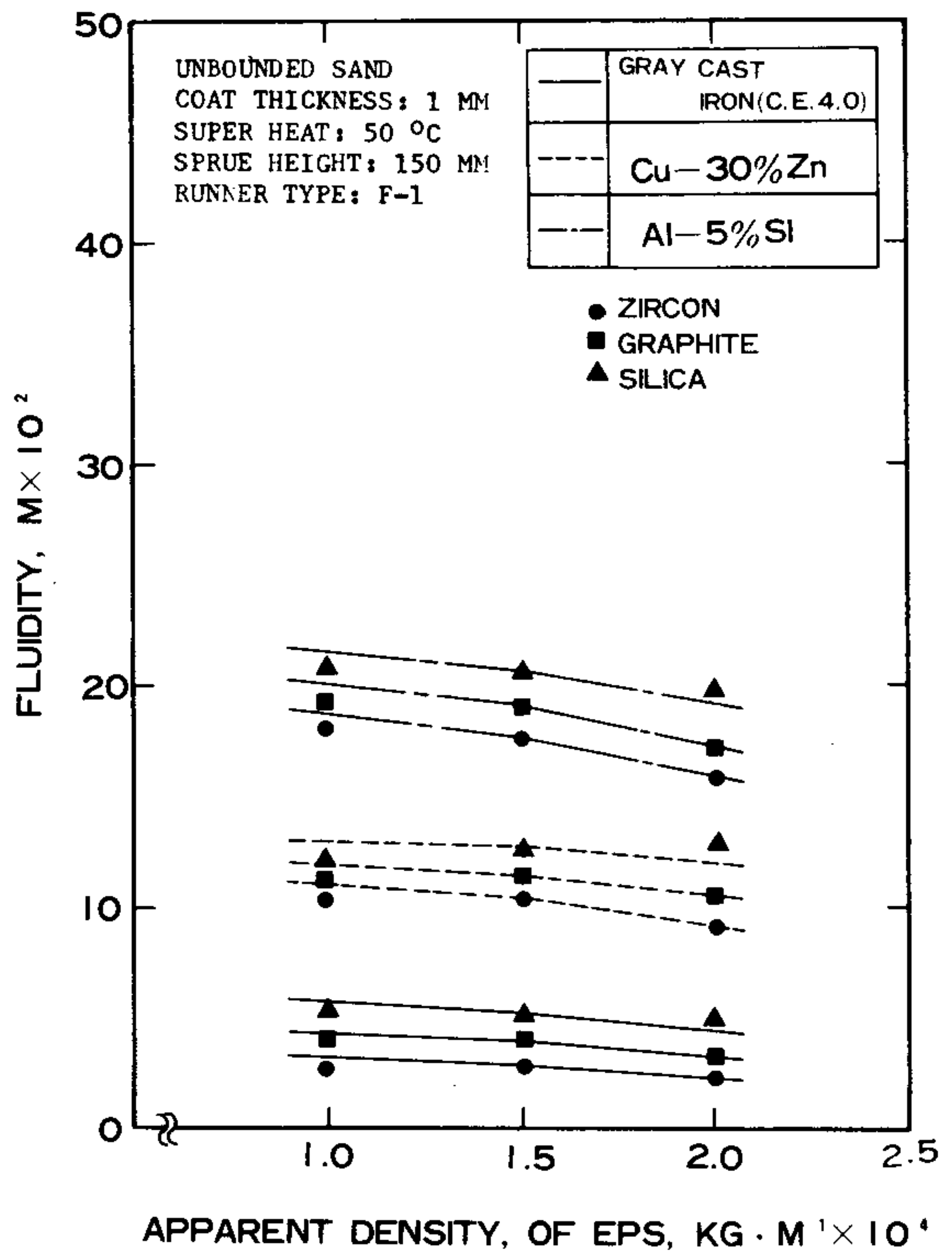


Fig. 11 Relationships between fluidity and apparent density of EPS pattern for three casting alloys with different coating material.

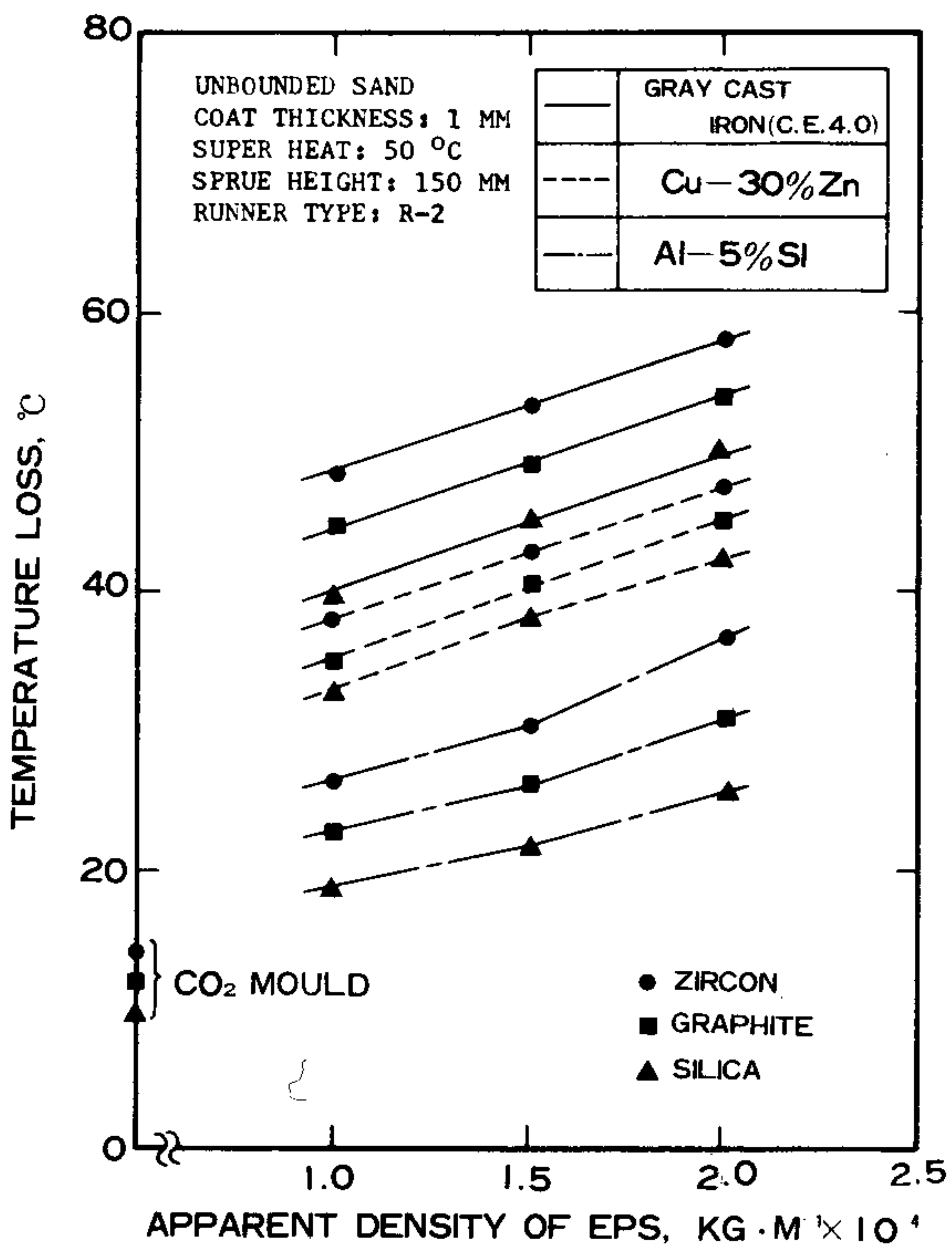


Fig. 12 Relationships between temperature loss and apparent density of EPS pattern for three casting alloys with different coating material

v : velocity of liquid stream tip (in m / s)
h : average interface heat transfer coefficient [in W / (m^2 · K)]
$\triangle$T : superheat, K
c' : specific heat of liquid metals, kJ / (kg · K)
Tm : melting temperature, K
To : mould temperature, K

Since the runner section is a square in this experiment, the equation (1) can be modified as below.

$$F \approx \frac{\rho_s \cdot l' \cdot V}{4 \cdot h \cdot (Tm - To)} \cdot (H + c' \cdot \triangle T) \qquad (2)$$

Where, l' : length of one side squared runner section for fluidity (in m)

Meanwhile, Jones et al[5] have calculated the heat loss to the gating system by an analytical method. The analytical method can easily be used by any foundryman. Temperature loss in a gating system is as follows :

$$T = \frac{P(\tau_0) \cdot (Tm - To)}{A \cdot \rho_l \cdot c'} \cdot \left(\frac{k \cdot \rho \cdot c}{\pi \cdot t}\right)^{\frac{1}{2}} \qquad (3)$$

Where, T : temperature loss of liquid metal (in K)
τ_0 : transit time of an element of metal (in s)
P : wetted perimeter (in m)
A : runner section area (in m^2)
ρ_l : density of liquid metal (in kg / m^3)
k : thermal conductivity of mould [in W / (m · K)]
ρ : density of mould (in kg / m^3)
c : specific heat of mould [in kJ / (kg · K)]
t : pouring time (in s)

This equation may be simplified further by means of following relationships :

$P = 4 \cdot l''$

where, l'': length of one side of squared runner section for temperature loss (in m)

$\tau_0 = t$ (to be assumed as transit time from location 1 to location 4)

$A = l''^2$

Substituting the above equations into equation(3) and simplifying, we get :

$$T = \frac{4 \cdot (Tm - To)}{l \cdot \rho_l} \cdot \left(\frac{k \cdot \rho \cdot c \cdot t}{\pi}\right)^{\frac{1}{2}} \qquad (4)$$

Combining the equations on fluidity and temperature loss, and if $P_S \approx P_L$, the equation(5) is given :

$$F = \frac{a}{T} \qquad (5)$$

where, $a = \frac{v}{2} \cdot \left(\frac{H + c' \cdot \triangle T}{h \cdot c'}\right) \cdot \left(\frac{k \cdot p \cdot c \cdot t}{\pi}\right)$

Since the temperature loss in the full mould is larger than that in the cavity mould, and fluidity in the full mould is smaller that in cavity moulds, the equation (5) can be expressed as belows.

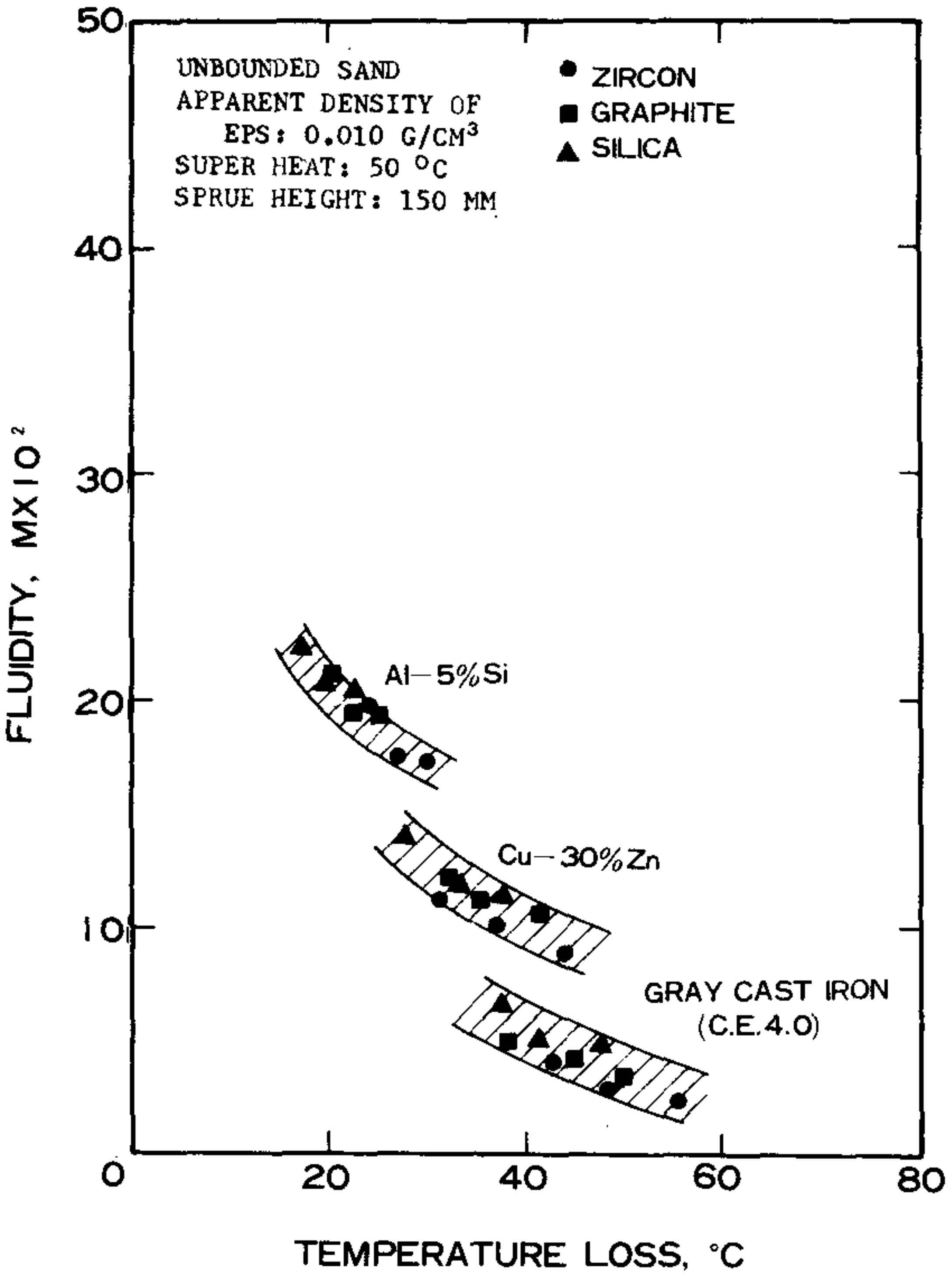


Fig. 13 Relationships between fluidity and temperature loss for three casting alloys with different coating material (applying EPS pattern with 0.5~1.5mm coating thickness)

$$F^* = \frac{a}{T^* - b} - c \qquad (7)$$

Where, F* : fluidity in the full mould (in m)
T* : temperature loss in the full mould (in ℃)
a : parameter for full mould
b, c : constants

Fig. 13 is showing a relationship between fluidity and temperature loss.

This illustrates that the bands which have upper and lower boundaries in the range of 0.5–1.5 mm coating thickness for ecah alloy.

Substituting this band shaped curves into equation⑸, a parameter for full mould casting can be determined. This value is a parameter for gas genaration and effects of coating materials in an practical full mould process.

In fact this value is considered to be used not only for clearing the relation between fluidity and temperature loss but also for calculating in ease the heat transfer coefficents which are difficult to be measured in full mould.

4. Conclusion

From the preceding results on effects of coating materials on fluidity and temperature loss of molten metals in full mould, the following conclusions are obtained.

1. Fluidity increases as runner section area, superheat and sprue height increase. Temperature loss decreases as runner section area and sprue height increase.
   However, a reversed effect is observed in the case of superheat increment.
2. The coating materials decrease the fluidity of each alloy in the order of silica, graphite and zircon. Zircon brings about the highest temperature loss among the coating materials used.
3. The fluidity increases in the order of gray iron, Cu−30% Zn and Al−5% Si alloy while temperature loss in the reverse order. Especially in case of reduced pressure process the fluidity is increased apparently.
   Al−5% Si alloy shows the lowest temperature loss among the alloys.
4. The increment of the apparent density of EPS pattern results in the fluidity decrease and temperature loss increase.
5. The relation between fluidity and temperature loss of each alloy can be expressed by the following equation within the coating thinkness limiy of 0.5−1.5 mm.

$$F^{*}=\frac{a}{T^{*}-b}-c$$

Where, F^{*} : fluidity in the full mould.
T^{*} : temperature loss in the full mould.
a : parameter for full mould.
b, c : constants.

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