**ISO**

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# Coke — Comparison of different tests used to assess the physical strength

*Coke — Comparaison des différents essais pratiques pour déterminer la cohésion*

## 0 Introduction

In the course of its work, the subcommittee ISO/TC 27/SC 3, *Coke*, received a considerable amount of experimental and other information relating the principal drum tests used in the assessment of the physical strength of coke and also the relevant strength indices. This Technical Report presents this information in a concise form.

## 1 Scope and field of application

This Technical Report describes the principal drum tests used to assess the physical strength of coke. These tests involve rotation of the coke in drums of different dimensions for different durations, and lead to the production of different indices. Additionally the available experimental evidence relating the various strength indices has been consulted. Such evidence relates the principal as well as secondary indices; in this Technical Report, all available statistical relationships between the principal strength indices have been listed and where possible illustrated graphically.

## 2 Definitions and symbols

For the purpose of this Report, the following definitions and symbols apply.

### 2.1 Drums

**2.1.1 ISO drum** : The drum described and defined in ISO 556[1], and used in the determination of Micum and Irsid indices. The dimensions given are those of the half-drum specified in that International Standard.

**2.1.2 JIS drum** : The drum described and defined in JIS K 2151-1972[2] and used in the determination of drum strength indices.

**2.1.3 ASTM drum** : The drum described and defined in ASTM D 3402-81[3] and used in the determination of hardness factor and stability factor.

### 2.2 Indices

**2.2.1 Micum index, $M_{40}$** : The percentage of the test sample, originally of particle size + 60 mm, remaining on or over a 40 mm aperture test sieve after 100 revolutions in the ISO drum.

**2.2.2 Micum index, $M_{10}$** : The percentage of the test sample, originally of particle size + 60 mm, passing a 10 mm aperture test sieve after 100 revolutions in the ISO drum. A loss in mass may be added, and this index is thus the complement to 100 of the percentage of the test sample remaining on or over the 10 mm aperture test sieve.

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**2.2.3 Irsid index, $I_{20}$** : The percentage of the test sample, originally of particle size + 20 mm, remaining on or over a 20 mm aperture test sieve after 500 revolutions in the ISO drum.

**2.2.4 Irsid index, $I_{10}$** : A similar index to the Micum index $M_{10}$, but taken from the percentage of the test sample, originally of particle size + 20 mm, passing a 10 mm aperture test sieve after 500 revolutions in the ISO drum.

**2.2.5 stability factor, $S$** : The percentage of the test sample remaining on or over a 25 mm aperture test sieve after 1 400 revolutions in the ASTM drum.

**2.2.6 hardness factor, $H$** : The percentage of the test sample remaining on or over a 6,3 mm aperture test sieve after 1 400 revolutions in the ASTM drum.

**2.2.7 JIS drum index, $DI_{15}^{30}$** : The percentage of the test sample remaining on or over a 15 mm aperture test sieve after 30 revolutions in the JIS drum.

**2.2.8 JIS drum index, $DI_{15}^{150}$** : The percentage of the test sample remaining on or over a 15 mm aperture test sieve after 150 revolutions in the JIS drum.

# 3 Methods of test

The physical dimensions of the drums and the detailed procedures adopted are given in full in the national and International Standards to which reference has been made.

However, for convenience in this Technical Report, the main dimensional and procedural features of the various tests have been given in table 1. It is emphasised that this table gives only a summary of the relevant information, and the appropriate standard should be consulted for fuller details.

# 4 Relationships between indices

The available relationships between the principal strength indices are given in the form of statistical regression lines. In most cases this is the limit to which the evidence can be presented, because the full experimental data are not given in the documents to which reference has been made. In some instances a correlation coefficient has been quoted and this further information is given in this Technical Report.

For the purpose of graphical representation, a few of the equations have been inverted in order to effect a change of base. This operation can introduce a small uncertainty, because the regression of $x$ upon $y$ is not necessarily the same as the regression of $y$ upon $x$. It is not considered that, in this context, the difference will be large, but the situation should be noted.

In the case of every relationship noted, the source of the information is given : the number given to each equation is the number of the appropriate source given in the Bibliography.

A summary of those pairs of indices between which relationships are noted is given in table 2.

Table 1 — Characteristics of drum tests

| Method | | ASTM | ISO (half-drum) | JIS |
|---|---|---|---|---|
| **Drum dimensions** | | | | |
| Internal diameter | mm | 914 | 1 000 | 1 500 |
| Internal radius, $r$ | mm | 457 | 500 | 750 |
| Internal length, $L$ | mm | 457 | 500 | 1 500 |
| **Lifting flights** | | | | |
| Number | | 2 | 4 | 6 |
| Depth of face | mm | 51 | 100 | 250 |
| Depth of transverse support, $t$ | mm | 51 | 63 | small |
| **Test sample** | | | | |
| Mass | lb | 22 | | |
| | kg | 10 | 25 | 10 |
| Lump size | in | 2-3 | | |
| | mm | | > 20 | > 50 |
| Sieve type | | square hole | round hole | square hole |
| Moisture | % | 1,0 max. | < 3,0 | 3 |
| **Rotation** | | | | |
| Angular velocity | rev/min | 24 | 25 | 15 |
| | | | Micum / Irsid | JIS K 2151-1960 / JIS K 2151-1972 |
| No. of revolutions | | 1 400 | 100 / 500 | 30 / 150 |
| **Strength indices** | | Stability factor = % > 1 in (25 mm) | $M_{40}$ = % > 40 mm / $I_{20}$ = % > 20 mm | $DI\,^{30}_{15}$ / $DI\,^{150}_{15}$ |
| | | Hardness factor = % > 1/4 in (6,3 mm) | $M_{10}$ = % < 10 mm / $I_{10}$ = % < 10 mm | Crushing strength = % > 15 / Crushing strength = % > 15 mm |

Table 2 — Summary of pairs of indices between which relationships are noted

| | $I_{10}$ | $I_{20}$ | $DI\,^{30}_{15}$ | $DI\,^{150}_{15}$ | $S$ | $H$ |
|---|---|---|---|---|---|---|
| $M_{10}$ | x | | x | x | x | x |
| $M_{40}$ | | x | x | x | x | |
| $DI\,^{30}_{15}$ | | | | | x | |
| $DI\,^{150}_{15}$ | x | | | | x | |

The relationships are presented in the following order :

a)  Micum $M_{40}$  and  ASTM stability factor, $S$

b)  Micum $M_{40}$  and  JIS $DI\,{}^{30}_{15}$

c)  Micum $M_{40}$  and  JIS $DI\,{}^{150}_{15}$

d)  Irsid $I_{20}$  and  Micum $M_{40}$

e)  Irsid $I_{10}$  and  Micum $M_{10}$

f)  Micum $M_{10}$  and  ASTM hardness factor, $H$

g)  ASTM stability factor, $S$ and Micum $M_{10}$

h)  Micum $M_{10}$  and  JIS $DI\,{}^{30}_{15}$

j)  Micum $M_{10}$  and  JIS $DI\,{}^{150}_{15}$

k)  JIS $DI\,{}^{30}_{15}$  and  ASTM stability factor, $S$

m)  Irsid $I_{10}$  and  JIS $DI\,{}^{150}_{15}$

n)  JIS $DI\,{}^{150}_{15}$  and  ASTM stability factor, $S$

p)  Mixed equations

a)  **Micum $M_{40}$ and ASTM $S$** (see figure 1)

i)  $M_{40}$  $= 1{,}24\,S + 17{,}8$ [4]

ii)  $S$  $= M_{40} - 20{,}1$ [5]
$(r = 0{,}983)$

Equivalent inverted form

$M_{40}$  $= S + 20{,}1$

iii)  $M_{40}$  $= 0{,}532\,S + 45{,}0$ [6]
(95 % limits $\pm\ 5{,}5$)

iv)  $S$  $= 1{,}1\,M_{40} - 28{,}8$ [7]

Equivalent inverted form

$M_{40}$  $= 0{,}90\,S + 26{,}18$

v)  $M_{40}$  $= 0{,}31\,S + 57{,}73$ [8]

vi)  $M_{40}$  $= 0{,}825\,S + 30{,}9$ [9]

vii)  $M_{40}$  $= 1{,}095\,S + 15{,}2$ [10]

viii)  $M_{40}$  $= 0{,}883\,S + 25{,}94$ [10]

ix)  $M_{40}$  $= 0{,}633\,S + 40{,}68$ [10]

x)  $M_{40}$  $= 0{,}3083\,S + 61{,}349$ [10]

b)  **Micum $M_{40}$ and JIS $DI\,{}^{30}_{15}$** (see figure 2)

i)  $M_{40}$  $= 3{,}15\,DI\,{}^{30}_{15} - 217{,}4$ [11]
$(n = 30,\ r = 0{,}702)$

ii) $DI\,_{15}^{30}$ = 70,07 + 0,30 $M_{40}$     [12]

$(n = 90, \; r = 0,81)$

Equivalent inverted form

$M_{40}$ = 3,33 $DI\,_{15}^{30}$ − 233,57

iii) $DI\,_{15}^{30}$ = 17,14 $(M_{40})^{0,39}$     [5]

$(r = 0,532)$

iv) $M_{40}$ = 1,85 $DI\,_{15}^{30}$ − 96,08     [8]

v) One unqualified relationship has been added to the figure, taken from document N 85     [15]

c) **Micum $M_{40}$ and JIS $DI\,_{15}^{150}$** (see figure 3)

i) $DI\,_{15}^{150}$ = 0,68 $M_{40}$ + 26,07     [12]

$(n = 29, r = 0,90)$

Equivalent inverted form

$M_{40}$ = 1,47 $DI\,_{15}^{150}$ − 38,34

ii) $M_{40}$ = 0,24 $DI\,_{15}^{150}$ + 55,18     [8]

d) **Irsid $I_{20}$ and Micum $M_{40}$** (see figure 4)

i) $I_{20}$ = 62,2 + 0,22 $M_{40}$     [13]

$(r = 0,60)$

ii) $I_{20}$ = 58,8 + 0,25 $M_{40}$     [13]

$(r = 0,57)$

iii) $I_{20}$ = 12,77 + 0,74 $M_{40}$     [16]

$(n = 70, r = 0,925, s = 1,775)$

e) **Irsid $I_{10}$ and Micum $M_{10}$** (see figure 5)

i) $I_{10}$ = 8,1 + 1,80 $M_{10}$     [13]

$(r = 0,90)$

ii) $I_{10}$ = 5,2 + 2,24 $M_{10}$     [13]

$(r = 0,78)$

iii) $I_{10}$ = 16,43 + 1,09 $M_{10}$     [16]

$(n = 70, r = 0,936, s = 1,464)$

f) **Micum $M_{10}$ and ASTM hardness factor, $H$** (see figure 6)

i) $M_{10}$ = 33,7 − 0,376 $H$     [9]

$(r = 0,853)$

ii) $H$ = 68,6 − 0,287 $M_{10}$     [5]

$(r = 0,504)$

Equivalent inverted form

$M_{10}$ = 239,0 − 3,48 $H$

g) **ASTM stability factor, $S$ and Micum $M_{10}$** (see figure 7)

$$S \quad = -2,62\,M_{10} + 73,9 \qquad\qquad [5]$$
$$(r = -0,801)$$

h) **Micum $M_{10}$ and JIS $DI_{15}^{30}$** (see figure 8)

   i) $M_{10} \quad = 62,97 - 0,58\,DI_{15}^{30}$ [8]

   ii) $M_{10} \quad = 102,0 - 0,99\,DI_{15}^{30}$ [11]
   $$(n = 30, \; r = 0,487)$$

   iii) $DI_{15}^{30} \quad = -1,54\,M_{10} + 103$ [5]
   $$(r = -0,691)$$

   Equivalent inverted form

   $$M_{10} \quad = 66,88 - 0,65\,DI_{15}^{30}$$

   iv) $DI_{15}^{30} = 102,38 - 0,97\,M_{10}$ [12]
   $$(n = 90, \; r = 0,68)$$

   Equivalent inverted form

   $$M_{10} \quad = 105,55 - 1,03\,DI_{15}^{30}$$

   v) One unqualified relationship has been added to the figure, taken from document N 85 [15]

j) **Micum $M_{10}$ and JIS $DI_{15}^{150}$** (see figure 9)

   i) $M_{10} \quad = 14,56 - 0,07\,DI_{15}^{150}$ [12]
   $$(n = 29, \; r = 0,64)$$

   ii) $DI_{15}^{150} = 102,19 - 2,37\,M_{10}$ [8]
   $$(n = 29, \; r = 0,64)$$

   Equivalent inverted form

   $$M_{40} \quad = 42,76 - 0,418\,DI_{15}^{150}$$

k) **JIS $DI_{15}^{30}$ and ASTM stability factor, $S$** (see figure 10)

   i) $DI_{15}^{30} \quad = 56,0\,(S)^{0,14}$ [5]
   $$(r = 0,968)$$

   ii) $DI_{15}^{30} \quad = 42,0\,(S)^{0,198}$ [8]

   iii) $DI_{15}^{30} \quad = 60,21 + 1,13\,S - 0,009\,46\,(S)^2$ [14]
   $$(n = 182, \; r = 0,84)$$

m) **Irsid $I_{10}$ and JIS $DI_{15}^{150}$** (see figure 11)

   $$I_{10} \quad = 120,35 - 1,19\,DI_{15}^{150} \qquad\qquad [15]$$

   (derived relationship from curve given)

n) **JIS** $DI_{15}^{150}$ **and ASTM stability factor,** $S$ (see figure 12)

$$DI_{15}^{150} = 38,32 + 1,25\,S - 0,008\,17\,S^2 \qquad [14]$$
$$(n = 161, r = 0,90)$$

p) **Mixed equations**

i) $DI_{15}^{30} = 78,800 + 0,243\,M_{40} - 0,481\,M_{10} \qquad [12]$
$$(n = 90, r = 0,87)$$

ii) $DI_{15}^{150} = 39,052 + 0,605\,M_{10} - 0,666\,M_{10} \qquad [12]$
$$(n = 29, r = 0,92)$$

## 5  Interpretation

In this Technical Report, a total of 40 relationships have been noted between the principal strength indices currently in use. Each has been derived from the statistical analysis of substantial experimental data, but each is only directly applicable to the specific conditions of sampling and testing employed in that exercise, and all relationships are subject to some degree of error or uncertainty.

The data are intended to give guidance to those desirous of seeking such relationships between coke strength parameters. They also indicate how further relationships may be derived from direct experimental evidence which are appropriate to specific conditions of the degree of coke stabilization and the point at which samples are taken. Where producers and consumers of coke are involved, an appreciation of the extent of coke degradation which occurs between the two points of sampling is necessary.
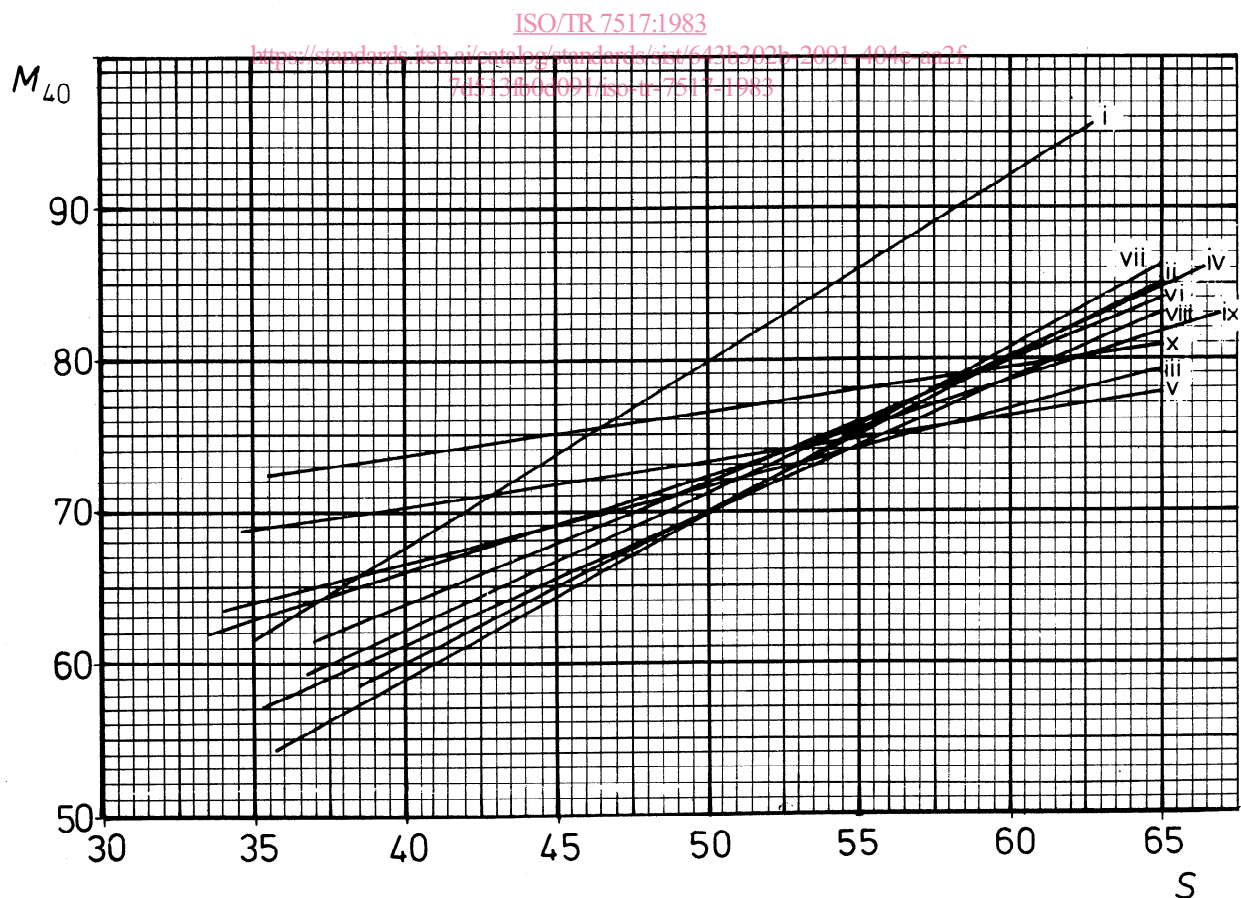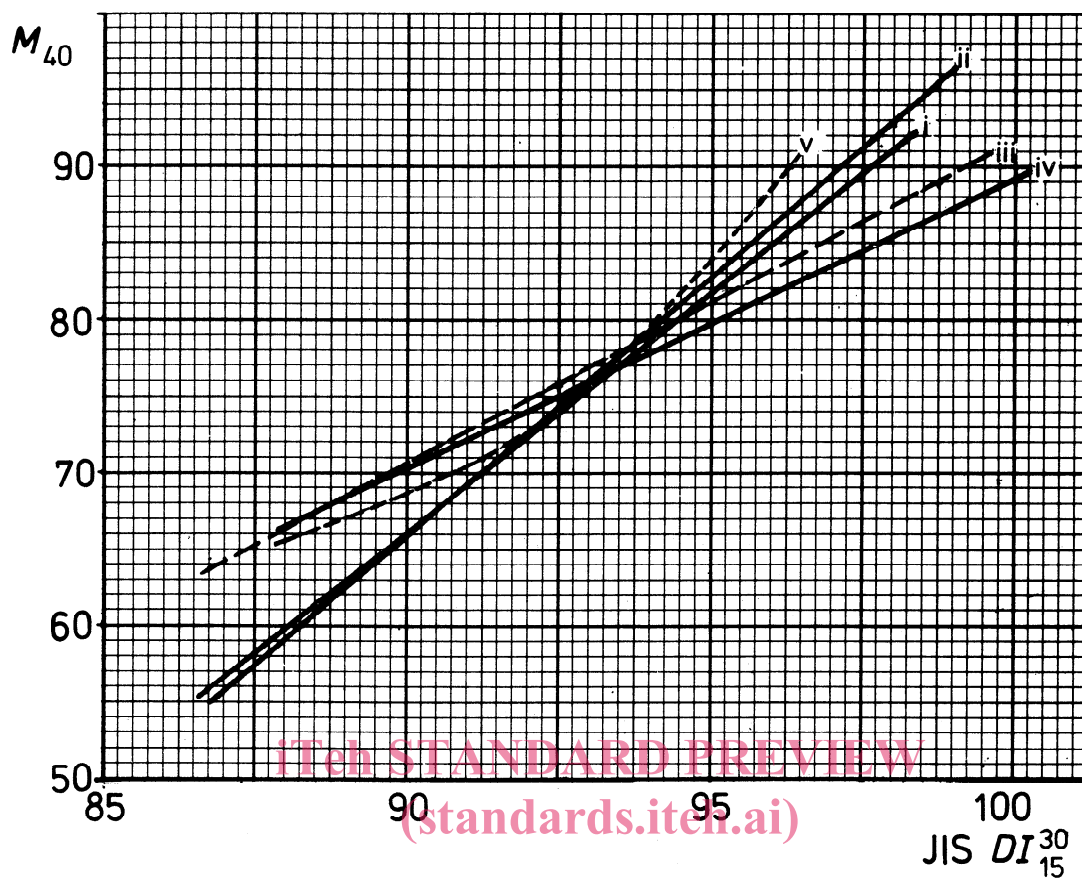
Figure 1 — Relationships between $M_{40}$ and $S$

Figure 2 — Relationships between $M_{40}$ and JIS $DI\,^{30}_{15}$
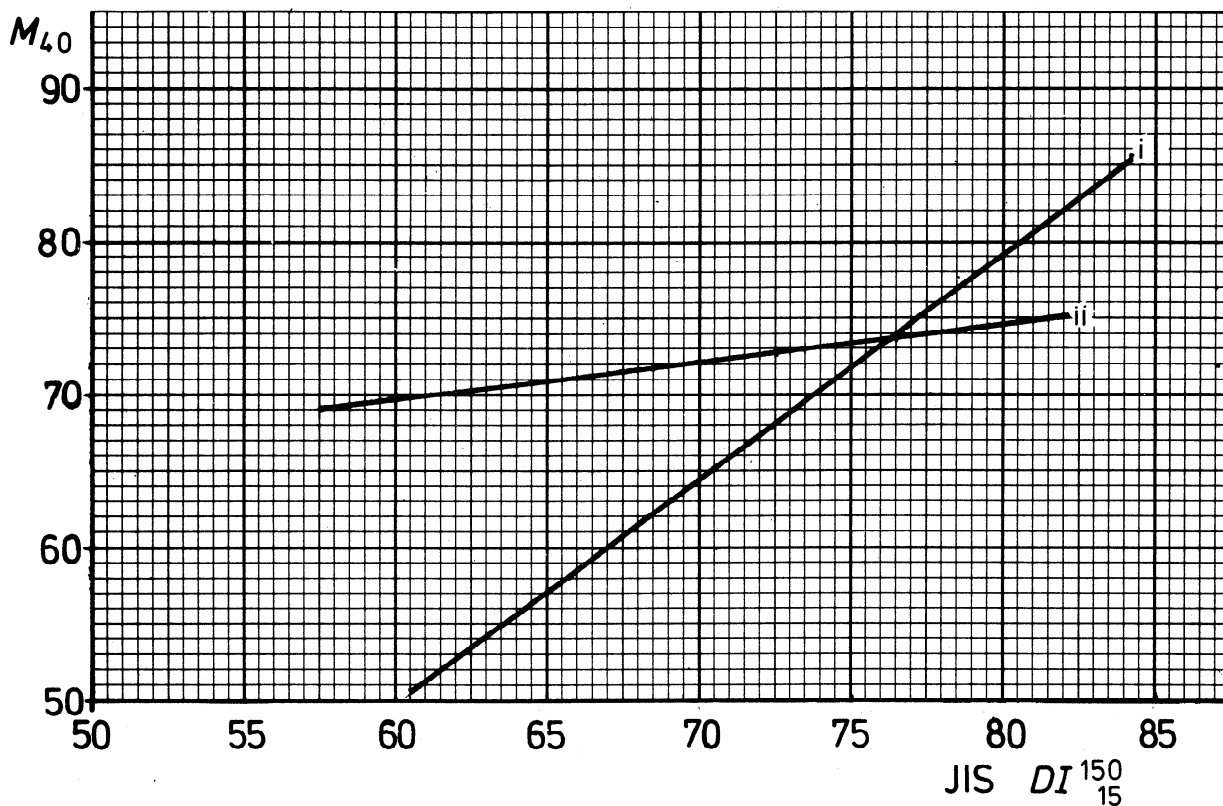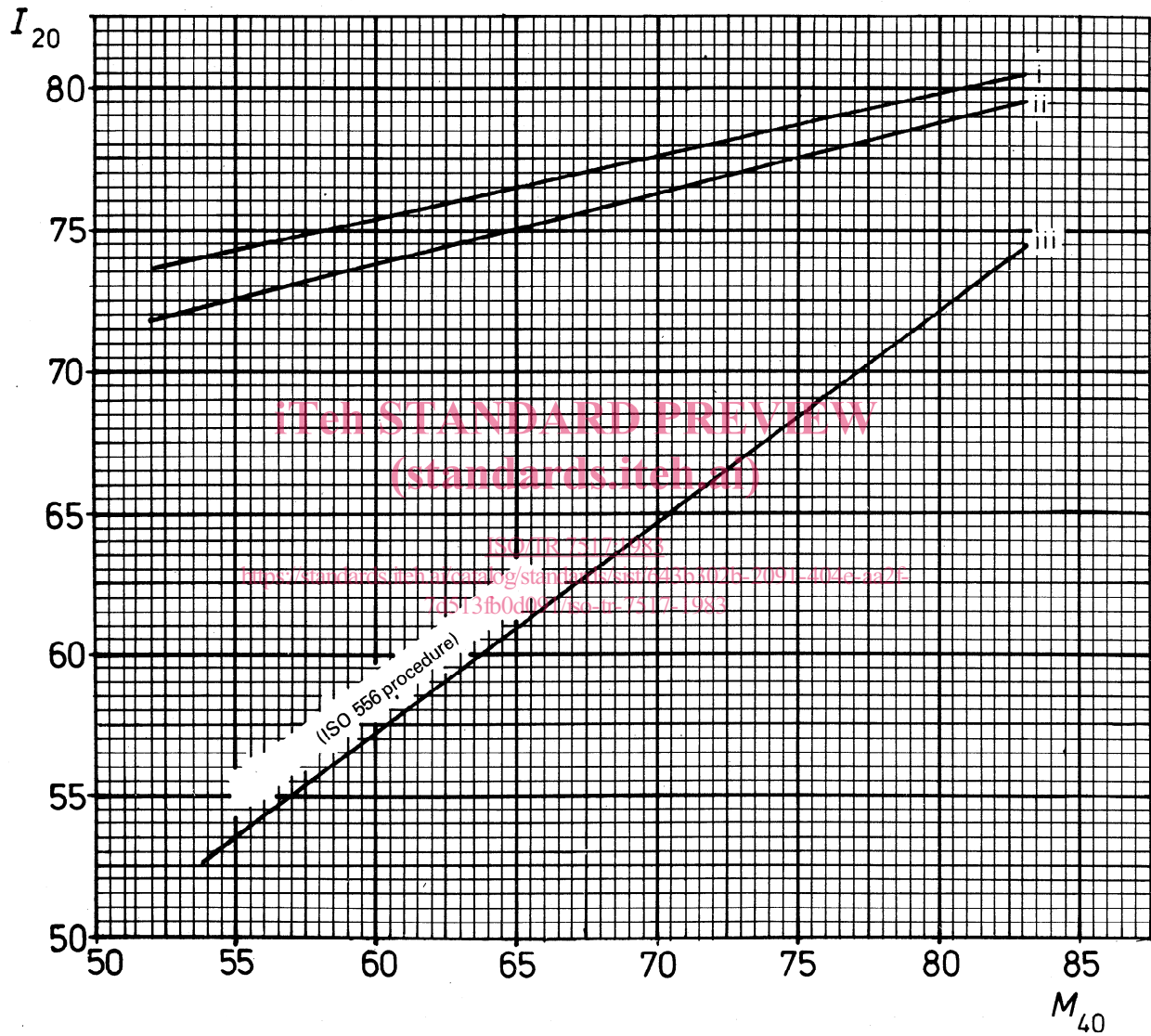


Figure 3 — Relationship between $M_{40}$ and JIS $DI\,^{150}_{15}$

**Figure 4 — Relationship between $I_{20}$ and $M_{40}$**