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CURIE TEMPERATURE OF ALLOYS, ITS MEASUREMENT AND TECHNICAL IMPORTANCE

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The basic relations between magnetic saturation and Curie temperature versus the composition is discussed for ferromagnetic metals and alloys of technical importance. There exist a number of methods for the determination of the transition from ferromagnetic to paramagnetic behaviour, i.e. thermogravimetry (thermomagnetometry), inductice methods and calorimetric methods.

As most non-magnetic solute elements lower the Curie temperature of ferromagnetic metals the Curie temperature can be used to determine the concentration of the solute element in binary systems up to the solubility limit.

In ternary and higher systems there is a combined effect of different element on the change of Curie temperature. Thus it is not generally possible to use the Curie temperature as a measure of the solute element concentration in such alloys. Under certain circumstances e.g. when the composition of a multiphase material is close to the equilibrium composition, it is still possible to use the Curie temperature to characterize the composition of the ferromagnetic phase. Such a system is exemplified by normal cobalt-based cemented carbide.

The Curie temperature can also be used as a means for temperature calibration, e.g. of thermobalances. Certified Reference Materials have been selected for this purpose by the ICTA Committee on Standardization.

DEFINITIONS AND SOME BASIC RELATIONS

Only a few elements of the periodic table are known to show ferromagnetism.

The most well-known elements are the three elements in the iron-group, viz. iron, cobalt and nickel. But at very low temperatures a number of elements in the rare-earth are also ferromagnetic, viz. gadolinium, terbium, dysprosium, holmium, erbium and thulium.

The ferromagnetic materials are characterized by spontaneous magnetization and that the magnetization reaches a very high level even when a relatively small external field is applied. When the external field is very strong, e.g. in the neighbourhood of 1 MA/m, also relatively large pieces of the ferromagnetic metals become saturated and comprise only a single domain. The saturation magnetization M_S decreases from its value M_O at the absolute zero temperature when the temperature is increased. When the material is heated further M_S falls rapidly to zero at a temperature named the Curie temperature, T_C. Above this temperature the material is paramagnetic.

If the spontaneous magnetization is normalized as a "reduced magnetization", M_S/M_O, and studied as a function of the "reduced temperature", T/T_C, the curves for the ferromagnetic elements Fe(BCC), Co(FCC), and Ni(FCC)are very similar and almost coincide [1]. It is thus to be expected that there exists a close relation between T_C and M_S.

According to Weiss this relation can be written [2]

$$T_C = \frac{J+1}{3J} \cdot \frac{\gamma}{k} \cdot \mu_m \cdot M_S$$

where J = total orbital impulse moment

γ = the molecular field constant

k = the Boltzmann constant

μ_m = the magnetic moment of a dipole

CURIE TEMPERATURES OF PURE ELEMENTS

The magnetic transformation temperature or Curie temperatures of pure, ferromagnetic metals are given in Table 1. There is an appreciable difference in the literature data, but those in the table seem to be the most preferred ones for high purity metals.

Cobalt exists in two ferromagnetic allotropic modifications, the low-temperature HCP phase and the high-temperature FCC phase. The phase transition temperature is reported to be between 388° and 450° [3]. By extrapolation of low-temperature data the Curie temperature of the HCP phase of cobalt has been estimated, see Table 1.

Table 1

Curie temperatures of ferromagnetic metals [3]

Metal	Allotropic modification	Curie temperature,	
		K	°C
Fe	BCC	1043	770
Co	FCC	1394	1121
Co	HCP /extra-polated/	1110	837
Ni	FCC	631	358

CURIE TEMPERATURE OF ALLOYS

Most alloying elements lower the Curie temperature of the ferromagnetic metals iron, cobalt and nickel, but iron and cobalt increase the Curie temperature of nickel and cobalt increases the Curie temperature of iron.

In many binary phase diagrams, the temperature dependence of solubility of several metallic solutes in iron, cobalt or nickel have a similar curvature. This curvature is generally approximated by an Arrhenius equation, in which the logarithm of the solubility is a linear function of the reciprocal absolute temperature [4,5]:

$$\ln x = K_1 + K_2/T$$

However, more thorough studies by, among other, Hillert et al. [6], Harvig et al. [7] and recently by Takayama et al. [8] have revealed anomalies of this solvus curve in the neighbourhood of the Curie temperature, see Fig. 1. The work of Hillert et al. [6] was an experimental test i.e. in the systems Fe-Mn and Fe-Ni of a model proposed by Zener [9] according to which

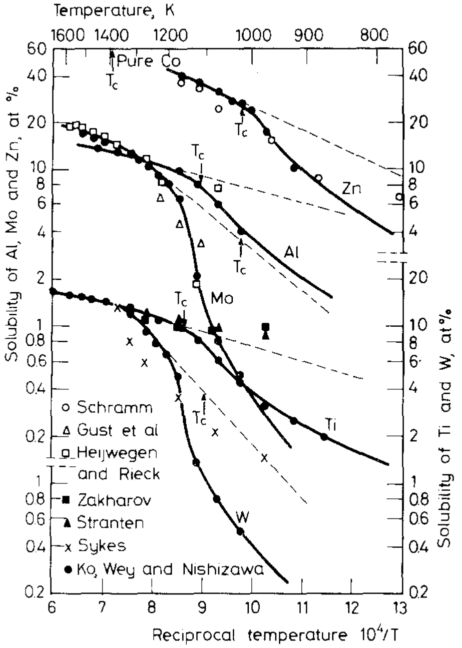

Fig. 1. Solubility of alloying elements in FCC cobalt [8]

there is an effect of Mn and Ni on the Curie temperature of BCC-Fe and on the standard free energy of reaction of the solutes when transferred from the BCC-Fe to the FCC-Fe. According to Zener the free energy of pure BCC-Fe can be split into a magnetic term and a non-magnetic term. When a small amount $\underline{x}$ of another element is alloyed in iron the Curie temperature is displaced a certain amount T_C and there is also a change in the free energy. Hillert et al. have described this relation according to the equation:

$$\left(\Delta^{\circ}G_{Y}^{\alpha\rightarrow\gamma\,\mathrm{Fe}}\right)_{\mathrm{Mag}} = \frac{1}{\Delta x}\cdot\Delta T_{c}\cdot\frac{\delta\left({}^{\circ}G_{\mathrm{Fe}}^{\alpha}\right)_{\mathrm{Mag}}}{\delta T} = -\frac{dT_{c}}{dx}\cdot\left({}^{\circ}S_{\mathrm{Fe}}^{\alpha}\right)_{\mathrm{Mag}}$$

Thus there is an intrinsic slope dT_C/dx of the Curie temperature *vs.* concentration curve which is specific for the solute element in question. This slope can be calculated if the influence of the alloying element upon the magnetic part of the free energy of the ferromagnetic metal is known, see Fig. 1. However, the reverse situation is usually the case and dT_C/dx-values have been used to evaluate this quantity.

Arita [10] has proposed a quasi-chemical model of ferromagnetic binary alloys containing a non-magnetic solute. He has discussed the free energies and enthalpies of mixing and also the effects of alloying on the Curie temperature. At low concentrations of the non-magnetic solutes he arrives at the following expression for the initial slope of the Curie temperature curve as a function of the concentration:

$$\left(\frac{dT_{c}}{dx_{2}}\right)_{x_{2}\doteq 0} = -\frac{4\chi kT_{c}^{2}}{j\eta^{4}z} = -\frac{4kT_{c}^{2}}{jz}\exp\left(\frac{-4w}{kT_{c}}\right)$$

where k = the Boltzmann constant

j = the exchange integral

w = the interaction energy of a pair of the two different atoms in question

z = the number of nearest neighbours of a lattice size

Arita has published a table of this initial slope of the Curie temperature curve, which covers the three ferromagnetic matals Fe, Co and Ni and the influence of 19 different non-magnetic metallic elements on this slope. By fitting calculated values to measured values of the slope he was able to determine the interaction energy $\underline{w}$. For values $\underline{w} > 0$ the Curie temperature decrease with composition is smaller than that for $\underline{w} < 0$. The theory fairly well describes the effects of addition of non-magnetic elements on the Curie temperature in the systems Co-Pt, Co-Mn and Fe-Zn.

MEASUREMENTS

Thermogravimetric methods

There are several methods available for measurements of the transition from the ferromagnetic to the paramagnetic state /or vice versa/ based upon the attraction force on the sample from a magnetic field. When this determination is made to study the influence of the temperature it is often called "thermomagnetometry". According to the ICTA Nomenclature committee [11] this term is defined as follows:

"A technique in which the magnetic susceptibility of a substance is measured as a function of temperature whilst the substance is subjected to a controlled temperature programme".

The earliest use of the gravimetric method for studies on magnetochemistry seems to have been made by Honda [12]. He was also the first to coin the word "thermobalance".

A determination of the Curie temperature of a cemented carbide binder phase sample by means of an automatic recording magnetic balance was presented already in 1958 by Nishiyama and Ishida [13]. The samples, weighing from 0.1 to 0.5 g, were sealed in evacuated silica capsules. The attraction force on the sample was less than 10 mg and it was recorded automatically with an x-y-recorder as a function of the temperature. They used rather fast heating and cooling rates, 100°/min, but still they were able to measure the Curie emperature with a reproducibility of approximately $\pm 10^\circ$.

During the latest decades there have been several publications on the use of thermobalances for thermomagnetometry [14--16]. The basic design has generally been the same, i.e. the sample in the furnace is subjected to a magnetic field gradient, generally from a permanent magnet. The necessary magnetic field strength is of the order of magnitude of 10-100 kA/m for Curie temperature measurements.

The magnetic forces acting on a ferromagnetic sample may sometimes be a result from the magnetic field of the furnace windings. Moskalewicz [17-19] has observed this effect in the thermoanalyzer "Derivatograph". When the furnace current has been switched on there is a displacement of the weight recording curve, but when the temperature increases over the Curie temperature the magnetic force acting on the sample disappears, see Fig. 2. Thus, an apparent weight change occurs and the time derivative gives a peak which coincides well with the Curie temperature. The method has been used to determine the Curie temperature of the iron group metals, spinels, garnets and ferrites [19].

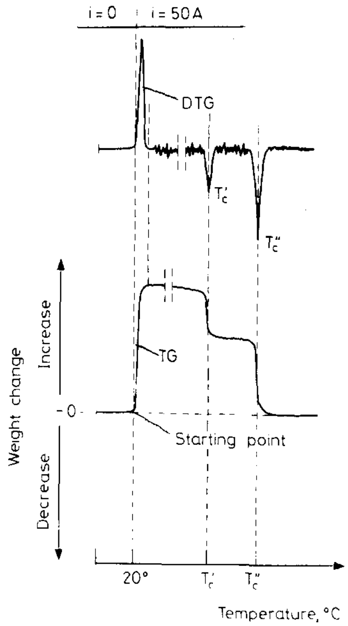

Fig. 2. Influence of magnetic forces on the weight recording [17]

Inductive methods

There is a number of methods described in the literature which make use of the change in permeability which occurs when a material is heated through its Curie temperature [20]. The sample can form a part of a tuned circuit and the change of frequency of an oscillator connected to this circuit is recorded when the temperature of the sample is changed. This method can be made very accurate and sensitive [21].

Another principle is based on the direct measurement of the permeability of the sample by measuring the impedance of a coil surrounding the sample. To compensate for changes in the coil resistivity the measurement is usually made in a differential mode with an empty coil as a reference [22]. The field strength used is of the order of magnitude 0.1-4 kA/m, depending on the sensitivity of the amplifier.

When magnetizing a ferromagnetic sample in a low-strength magnetic field the magnetic permeability first increases with an increase in temperature up to a maximum slightly below the Curie temperature. Then the permeability drops sharply to zero. Tumanov et al. [22] define the Curie temperature as the temperature at the intersection between the extrapolation of the descending branch of the curve and the zero value of permeability.

The inductive method for Curie temperature determination can be used within an extremely wide range of temperatures from almost absolute zero to at least 1100-1200^{o}. The main problem is to keep the magnetic coils separated from the sample and structural parts of the apparatus at extreme temperatures. This often necessitates a very sensitive detector device as the distance to the sample may be comparatively large.

The Foner magnetometer

For determination of the saturation magnetization and of the Curie temperature the so-called Foner magnetometer can also be used [23]. In this instrument the sample has been fastened to a vertical rod in the gap of the magnet, see Fig. 3. The rod vibrates at a low freuency /e.g. 70 Hz/. When the sample vibrates an alternative voltage is induced in two detector coils which are situated between the sample and the pole pieces of the magnet. On the other end of the rod another small permanent magnet is fastened, which when vibrating induces an alternative voltage in two reference coils.

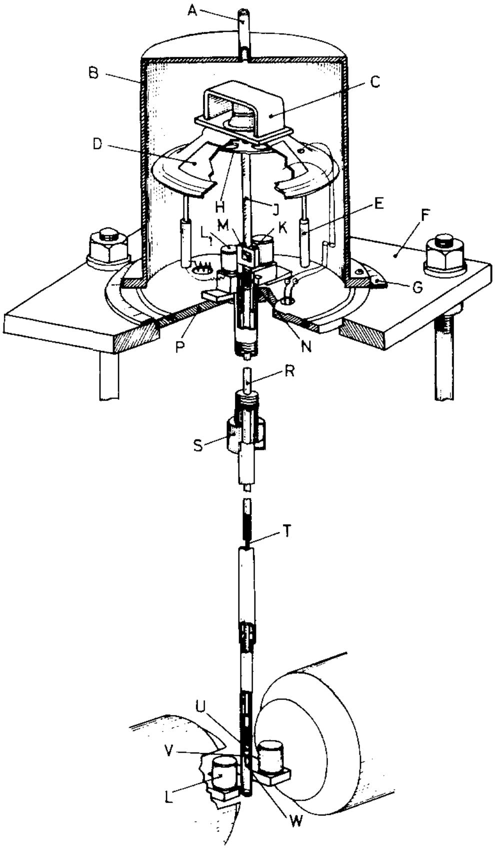

Fig. 3. The Foner magnetometer [23]

The two induced voltages are compared at 180° phase shift in a lock-in amplifier and the attenuation necessary to obtain zero output from the amplifier is taken as a measure of the magnetization of the sample.

The Foner magnetometer can also be used within a wide temperature range. When a helium cryostat is used it can measure down to approximately 2 K.

Calorimetric methods

The transition from the ferromagnetic to the paramagnetic state is accompanied by a sharp peak in the specific heat capacity [24] due to the second-order transition. This is evident from the enthalpy vs. temperature curve, in which the slope sharply increases around the Curie temperature [25], see Fig. 4.

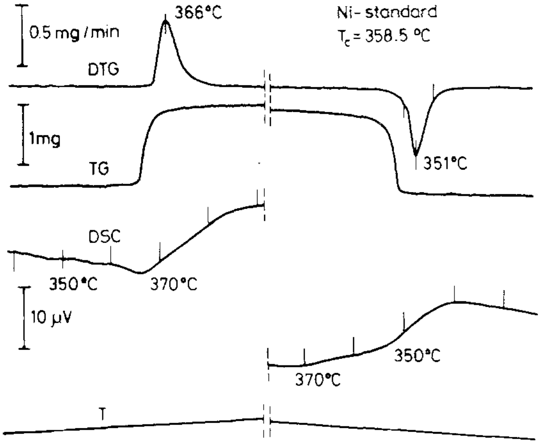

Fig. 4. Differential scanning calorimetry /DSC/ and thermomagnetometry /TG and DTG/. Curves of pure nickel. Heating rate: 10 degree/min

This discontinuity depends on an exchange interaction between the spins of closely lying electrons. If two different metals are mixed into a magnetic alloy the exchange interaction energy of the d-electrons might be of the same order of magnitude or even larger than the heat of mixing of the two metals. Thus one might expect a pronounced difference in the thermodynamic properties of the alloy in the ferromagnetic state as compared to the paramagnetic state.

Differential thermal analysis /DTA/ or differential scanning calorimetry /DSC/ are methods which are very well suited to study this change in specific heat capacity at rising or descending temperatures. Figure 4 shows such an example for nickel around its Curie temperature, together with the corresponding thermogravimetric curve.

APPLICATIONS

Control of dissolved elements in ferromagnetic alloys

Most solute elements lower the Curie temperature of the alloys continuously to the point where the Curie temperature curve intersects the solubility curve. In alloys with a composition within the two-phase field the Curie temperature remains constant. Thus, the Curie temperature can be used to determine the concentration of the solute element in a binary system up to the solubility limit.

In ternary and higher systems there is a combined effect of the different solute elements. Thus it is not possible to use only the Curie temperature as a measure of the solute elements in a single-phase alloy. On the other hand, if the alloys also contain one or more extra phases precipitated from the ferromagnetic phase after an equilibrium treatment at a temperature followed by quenching, it should be possible to use the Curie temperature and the solubility curve of the precipitated phase to estimate the content of the dissolved elements in the ferromagnetic phase.

Phase transformations

Curie temperature measurements can be used for studying the presence of magnetic phases in alloys at different stages during thermal treatment. Thus thermomagnetometry can provide complementary information to other methods, e.g. X-ray diffraction, electron microprobe analysis combined with microstructural studies at different magnifications as well as differential scanning calorimetry. All these methods have different features which make them more or less suitable for studying various transitions. As thermomagnetometry is rapidly performed and also often can be made to simulate a true heat treatment cycle it can give information which is difficult or even impossible to obtain by other methods.

An example is shown by Gallagher et al. [26] who studied phase changes in a magnetic alloy, Chromindur II. This is an iron-based alloy with 28% Cr and 10.5% Co which undergoes a metastable spinodal decomposition below 650° after previous solution treatment. To obtain optimum isotropic permanent magnetic properties it is thus necessary to use a proper aging heat treatment.

Gallagher et al. studied the decomposition products by thermomagnetometry and found two products, one Cr-rich near-equilibrium product which was less magnetic and had a lower Curie temperature and one Cr-deficient product which was more magnetic and with a Curie temperature equal to or slightly below 720°. The phase diagram for the metastable system shows that the quenched sample consists essentially of unstable single phase alpha /BCC/ material. When heat-treated in the region of immiscibility this material tends to disproportionate into 1 and 2 metastable products with compositions depending on the kinetics of the system and the heating rate.

When reheating the quenched alloy at a fast heating rate, 160° min^{-1}, the extent of the spinodal decomposition was almost nil and the thermogravimetric curve can be regarded as representative of the pure alpha phase. The apparent weight loss occurred in a very narrow temperature range at 640-650° and resulted in a very sharp peak on the DTG curve. The conclusion was that the single phase alpha alloy /with 28% chromium/ has a Curie temperature of 650°.

At slower heating rates the thermomagnetometry curves showed a resolved behaviour due to the presence of decomposition products with higher and lower chromium contents than the parent alpha alloy. Thus if such a resolved behaviour is observed it reveals whether the alloy had undergone significant spinodal decomposition during prior thermal history.

The chromium-rich intermediate or equilibrium spinodal decomposition product is less magnetic and its Curie temperature may be as low as 590°. Due to a strong exchange coupling with the phase having higher Curie temperature it is not always possible to detect the Curie temperature of the less magnetic phase as its demagnetization may be prevented by the other phase. The criterion for detection seems to be a phase boundary separation beyond approximately 100 nm.

Cemented carbides

Cobalt-based grades

Already in 1961 Fukatsu [27] studied the structure and properties of binder phase alloys of compositions corresponding to those of WC-Co cemented carbide. He studied i.a. the magnetization curves vs. the temperature as a function of the tungsten carbide in solid solution in cobalt, see Fig. 5. He found the relation

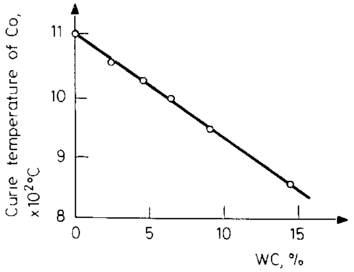

Fig. 5. Curie temperature of solid solutions of cobalt binder phase in WC-Co alloys [27]

$$T_C^x = T_C^{Co} - 17x_{WC}$$

where T_C^x = the Curie temperature of the alloyed cobalt binder phase

T_C^{Co} = the Curie temperature of the pure cobalt

x_{WC} = the concentration of WC/wt %/ in solid solution.

Fukatsu also found that the shape of the thermomagnetic curve depended on the heat treatment of the alloy studied. For example, an alloy consisting of large dendrites of /W,C/-containing cobalt surrounded by a fine-dispersed cobalt-eta phase /Co_3W_3C/ eutectic exhibited two distinct steps in the magnetization-temperature curve. The reason for this must be a strong segregation of tungsten /and carbon?/ in the cobalt phase, thus indicating a very heterogeneous composition.

After a homogenization heat treatment at 1260°, 60 h, the thermomagnetic curve showed the normal shape, similar to that of pure ferromagnetic elements. The microstructure of this alloy consisted of finely dispersed tungsten carbide grains in a matrix of /W,C/-alloyed cobalt. Obviously the alloy had been carburized during the heat treatment and the eta phase had decomposed to cobalt and tungsten carbide.

This early example shows the impact of the thermomagnetometry in a brilliant way!

Nishiyama and Ishida [13] investigated the cobalt binder phase of several types of cemented carbide grades containing not only Co and WC, but also TiC and /Ta,Nb/C. They used i.a. X-ray diffractometry to determine the lattice parameter of the cobalt binder phase and also thermomagnetometry to study the magnetization curve. They found that the cobalt binder phase of cemented carbide always has a lower Curie temperature than that of cobalt saturated with carbon. This indicates that the binder phase always contains more or less tungsten and also /according to Nishiyama and Ishida/ fairly large amounts of various other elements in solid solution at room temperature. They also found that the content of the metallic solute in solid solution is large when the carbon content of the cemented carbide is low, which is in accordance with later findings and what could be expected from the equilibrium diagram [28-30].

When comparing the presumptive contents of solute atoms estimated by lattice parameter determination and by Curie temperature determination Nishiyama and Ishida were unable to deduce a mutual relationship. This fact was explained to be the result of dissolution of fairly large amounts of "impurity atoms" i.e. carbon, tungsten, titanium, tantalum and niobium in cobalt.

Later studies [31] have, however, not confirmed that any appreciable amounts of titanium, tantalum or niobium are present in the binder phase. It is thus suggested that the Curie temperature of normal cobalt-based cemented carbide alloys is, approximately, a function of only the carbon and tungsten contents the binder phase [15].

In cobalt-rich cemented carbide grades it is possible to find binder phase areas which are sufficient large for a reliable microprobe analysis of the dissolved amount of tungsten [32].

A linear relationship has been obtained between the tungsten content analyzed in the microprobe and the content derived from the Curie temperature [15] see Fig. 6. The standard deviation of the analyzed tungsten content is larger in the microprobe results than of the values obtained from the Curie temperature results, but this difference might also be a true effect of a local variation of the content of tungsten in solid solution in the binder phase.

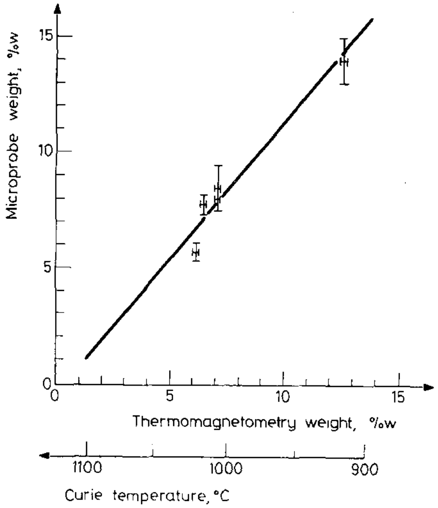

Fig. 6. Comparison of tungsten contents of binder phases in WC-Co alloys determined by Curie temperature measurements and by microprobe analysis [32].

In cemented carbide alloys of the cobalt-tungsten carbide type the tungsten content of the binder phase is mainly determined by the carbon activity previaling during the sintering. In general terms a high carbon activity lowers the tungsten content drastically but a low carbon activity increases the tungsten content [30].

So far no complete investigation of the combined effect of tungsten and carbon on the Curie temperature has been found, but Suzuki and Kubota [33] reported the relationship between the carbon content of a WC - 10 % % Co alloy and the Curie temperature. They also reported the influence of the carbon content on the magnetic saturation in the same diagram.

Nickel-based grades

Cemented carbide grades having titanium carbide as the predominant hard constituent generally have nickel or nickel alloys as binder phase. This implies that the Curie temperature of such alloys is low in comparison to cobalt-based cemented carbide grades.

Due to the high value of the free energy of formation of titanium carbide the solubility in the nickel binder phase is relatively low. Still, the Curie temperature is lowered drastically by the dissolution of titanium.

Lönnberg and Smith [34] studied the Curie temperature and saturation magnetization of single-phase nickel-based titanium--carbon alloys. These were homogenized at 1150^o and quenched. The Foner magnetometer was used for the magnetic measurements. The results of the saturation magnetization is shown in Fig.7, the Curie temperatures in Fig. 8 and the linear relationship between these properties in Fig. 9. From these results the values of Weiss' molecular field constant has been determined to 2600.

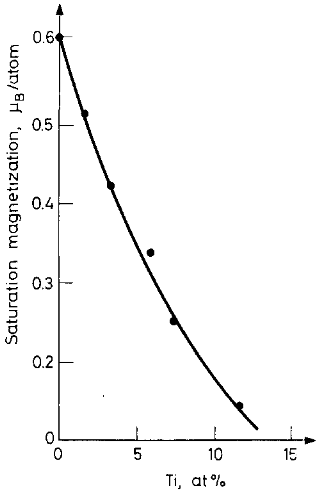

Fig. 7. Saturation magnetization of Ni/Ti/-alloys vs. titanium content [34].

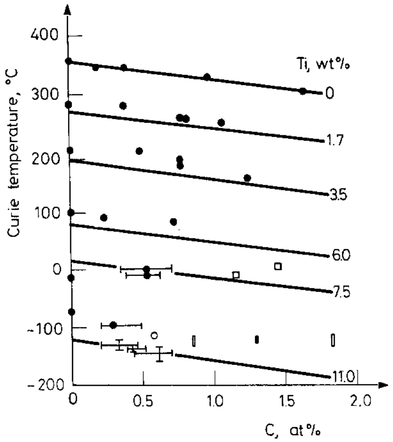

Fig. 8. Curie temperature of Ni/Ti,C/-alloys vs. titanium and carbon contents [34].

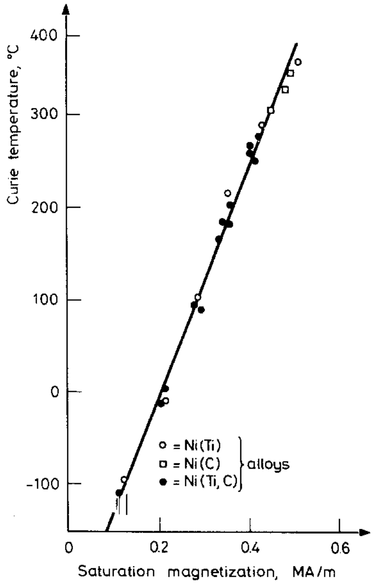

Fig. 9. Curie temperature vs. saturation magnetization for Ni/Ti,C/-alloys [34].

Use of the Curie temperature for calibration purposes

In most thermobalances the temperature of the sample is measured at some distance from the sample /or reference material/. As thermal analysis generally is performed at a certain rate of heating or cooling and as there always exists a temperature gradient inside the furnace, the measured temperature generally differs more or less from the true temperature of the sample. To be able to correct for this difference the ICTA Committee on Standardization recommends the use of Curie temperature measurement on a series of Certified Reference Materials with recognized Curie temperatures [35]. This series of reference materials is supplied by the U S National Bureau of Standards under the Code No GM-761 and comprises the five materials given in Table 2.

Table 2.

Materials of ICTA Curie temperature standards [36]

Material	Approximative transition temperature, °C
Permanorm 3	259
Nickel	353
Mumetal	381
Permanorm 5	455
Trafoperm	751

The exact definition of the transition temperature, the use and the evaluation of the results obtained with these reference materials is described in detail in the Certificate, which is supplied with the reference materials [36,37].

Artifacts in thermogravimetry introduced by ferromagnetic samples

Gallagher et al. [38] have reviewed and reinvestigated work of other authors which claim to have found a pronounced effect of an external magnetic field on the reaction rate of materials below their magnetic transition temperature. This effect was found in thermogravimetric studies of the reduction rates of some oxides of iron [39] and cobalt [40].

Gallagher et al. used a complimentary technique to thermogravimetry, namely evolved gas analysis /EGA/. This technique is not sensitive to any influence of external magnetic fields on the sample and Gallagher et al. was also unable to reproduce the claimed influence of the magnetic field on the reduction rate. The earlier results [39,40] which imply such an influence were thus suggested to be artifacts brought on by magnetic forces on the samples.

Similar magnetic effects on thermogravimetric measurements can also result from the interaction between a ferromagnetic sample and strong magnetic fields e.g. from the furnace windings, see for instance Moskalewicz [17].

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ZUSAMMENFASSUNG - Die grundlegenden Beziehungen zwischen der magnetischen Sättigung und der Curie-Temperatur von technisch wichtigen ferromagnetischen Metallen und Legierungen einerseits und der Zusammensetzung anderseits werden diskutiert. Eine Reihe von Methoden zur Bestimmung des Übergangs vom ferromagnetischen zum paramagnetischen Verhalten sind bekannt, nämlich Thermogravimetrie (Thermomagnetometrie) sowie induktive und kalorimetrische Verfahren.

Da die meisten nichtmagnetischen Legierungselemente die Curie-Temperatur des ferromagnetischen Metalls herabsetzen, kann die Curie-Temperatur zur Bestimmung der Konzentration des gelösten Elements in binären Systemen bis zur Löslichkeitsgrenze herangezogen werden.

In ternären und komplexeren Systemen kommt es zu einer kombinierten Wirkung der verschiedenen Elemente auf die Veränderung der Curie-Temperatur. Es ist somit nicht generell möglich, die Curie-Temperatur zur Messung der Konzentrationen der in solchen Legierungen gelösten Elemente heranzuziehen. Unter bestimmten Umständen, z.B. wenn die Zusammensetzung des Multiphasen--Materials nahe der Gleichgewichtszusammensetzung liegt, ist es noch möglich, die Curie-Temperatur zur Charakterisierung der Zusammensetzung der ferromagnetischen Phase zu benutzen. Ein Beispiel für ein solches System ist normales, auf Kobalt-Basis zementiertes Karbid.

Die Curie-Temperatur kann auch zu Temperaturkalibrationen von z.B. Thermowaagen herangezogen werden, wofür vom ICTA-Komitee für Standardisierung Standard-Referenzsubstanzen gesammelt wurden.

Резюме - Для технически важных ферромагнитных металлов и сплавов обсуждены главные зависимости магнитного насыщения, температуры Кюри от состава. Существует ряд методов определения переходов из ферромагнитного состояния в парамагнитное: термогравиметрический /термомагнетометрия/, индукционные и калориметрические методы. Поскольку большинство немагнитных элементов, растворенных в ферромагнитных металлах, понижают температуру ферромагнетиков, то температура Кюри может быть использована для определения в двойных системах концентрации растворенного элемента вплоть до предела его растворимости. В тройных и более сложного состава системах наблюдается сложное влияние различных элементов на изменение температуры Кюри. Поэтому в та-

ких сплавах невозможно в общем использовать температуру Кюри, как меру концентрации растворенного элемента. При определенных обстоятельствах, когда, например, состав многофазового материала близок к равновесному составу, все еще возможно использовать температуру Кюри для характеристики состава ферромагнитной фазы. Примером такой системы служили цементированные карбиды с кобальтом. Кроме того температура Кюри может быть использована для температурной калибровки термовесов. Для этой цели были взяты "проверенные реперные материалы", согласно стандартизационному комитету ICTA.