Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

$K_0, K_1, K_2, K_3, K_4, K_5, K_6$ CONSTANTS EVALUATION OF MAGNETO-CRYSTALLINE ANIOSOTROPY ENERGY DENSITY EQUATION OF PURE IRON BASED ON TEXTURE FACTOR FOR IDEAL FIBRES

Geruganti Sudhakar, orcid:0009-0000-0039-7536, Phd Research Scholar (Material Engineering), School of Engineering ScienceandTechnology,University of Hyderabad,Hyderabad,India.
Email:20etpm09@uohyd.ac.in

Abstract
Texture Factor, A* and Magnetic Crystalline Anisotropy Energy Density* $K_0, K_1, K_2, K_3, K_4, K_5, K_6$ Constants are important parameters for Pure Iron. While the former indicates volume density of crystals having preferred Orientation, latter indicates the easy and hard magnetization directions. Evaluation of these parameters for Pure Iron and Electrical Steel enables in reduction of core losses and improving the electrical energy efficiency in Transformers, Rotating Machines. In this research article, an attempt is made to compute Magneto-Crystalline Anisotropy Energy Density for pure iron based on Texture Factor for Ideal fibers.

Keywords: Texture Factor, Magnetic Crystalline Anisotropy Energy Density, Core losses

I. INTRODUCTION:

The Magneto Crystalline Anisotropy constants $K_0, K_1, K_2, K_3, K_4, K_5, K_6$ values determine the extent to which a material is easily magnetizable. Their value depends on Chemical Composition, Crystal Structure, and Thermo-Mechanical Processing history of the given material. Texture factor constants $K_0, K_1, K_2, K_3, K_4, K_5, K_6$ values determines the preferred orientations of grains, the Overall Texture Factor is quantitative measurement of texture. Texture Factor is an important microstructural parameter which directly determines the anisotropy degree of most physical properties of a polycrystalline material at the macro scale. Its characterization is thus of fundamental and applied importance, and should ideally be performed prior to any physical property measurement or modeling. Neutron diffraction is a tool of choice for characterizing crystallographic textureS. The obtained information is representative of a large number of grains, leading to a better accuracy of the statistical description of texture.Texture factor constants K_0, K1, K2, K_3, K_4 values determines the preferred orientations of grains, the Overall Texture Factor is quantitative measurement of texture. The value signifies extent of presence of standard texture viz. Cube Texture (T.F = 22.5), Goss Texture (T.F = 35.6), Gamma Texture (T.F = 38.68) in the given material

1.1 ESTIMATION OF MAGNETIC ANISOTROPY CONSTANTS $K_0, K_1, K_2, K_3, K_4, K_5, K_6$ CONSTANTS EVALUATION OF FOR ELECTRICAL STEELS:

Magneto Crystalline Anisotropy Energy is generally expressed by an expansion into direction cosines α_1, α_2, α_3 of the magnetization with respect to the crystal axes.

$E^* = K_0 + K_1 (\sum\alpha^2_1 \alpha^2_2) + K_2 (\prod\alpha^2_1) + K_3 (\sum\alpha^2_1 \alpha^2_2)^2 + K_4 (\sum\alpha^2_1 \alpha^2_2)(\prod\alpha^2_1) + K_5 (\sum\alpha^2_1 \alpha^2_2)^3 + K_6 (\prod\alpha^2_1)^2$ [I];

[uvw]	a	b	c	α_1	α_2	α_3	E
[100]	0	90^0	90^0	1	0	0	K_0
[110]	45^0	45^0	90^0	$1/\sqrt{2}$	$1/\sqrt{2}$	$1/\sqrt{2}$	$K_0 + K_1/4$
[111]	54.7^0	54.7^0	54.7^0	$1/\sqrt{3}$	$1/\sqrt{3}$	$1/\sqrt{3}$	$K_0 + K_1/3 + K_2/27$

From REF 1, we have

E* = 0.355A* +(0.163 – 0.013A*)[wt%Si] -1.898

FOR **A* for Θ fiber <100>//ND is 22.5 => E* = 6.0895**

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

FOR **A* for fiber <110>//ND is 35.6 => E* = 10.74**
FOR **A* for ϒ fibre <111>//ND is 38.68 => E* =11.8334**

$E^* = K_0 + K_1 (\sum\alpha^2_1 \alpha^2_2) + K_2 (\prod\alpha^2_1) + K_3 (\sum\alpha^2_1 \alpha^2_2)^2 + K_4 (\sum\alpha^2_1 \alpha^2_2)(\prod\alpha^2_1) + K_5 (\sum\alpha^2_1 \alpha^2_2)^3 + K_6 (\prod\alpha^2_1)^2$ .....[I]

FOR [100] directions, $\alpha_1 = 1$, $\alpha2 = 0$, $\alpha_3 = 0$

- **$E^* = K_0 = 6.0895$**

FOR [110] directions, $\alpha_1 = 1/\sqrt{2}$, $\alpha2 = 1/\sqrt{2}$, $\alpha_3 = 0$

- **$E^* = 6.0895 + K_1/4 + K_3/16 + K_5/64$**
- **$10.74 = -0.5345\,[wt\%Si] + 6.0895 + K_1/4 + K_3/16 + K_5/64$**
- **$(4.6505)*64 = 16K_1 + 4K_3 + K_5$**
- **$16K_1 + 4K_3 + K_5 = 297.632$ [II]**

FOR [111] directions, $\alpha_1 = 1/\sqrt{3}$, $\alpha2 = 1/\sqrt{3}$, $\alpha_3 = 1/\sqrt{3}$

- **$11.8334 = 6.0895 + K_1/3 + K_2/27 + K_3/9 + K_4/81 + K_5/27 + K_6/729$**
- **$27(9K_1 + K_5 + 3K_3) + (9K_4 + 27K_2 + K_6) = 4187.3031$**
- **$27(150) + 137.3031 = 4187.3031$**
- **$(9K_1 + K_5 + 3K_3) = 150$; ….[III]**
- **$(9K_4 + 3K_2 + K_6) = 137.3031$ ….[IV]**
- **SUBSTRACTING [III] and [II],we have**
- **$16K_1 + 4K_3 + K_5 = 297.632$**
- **$9K_1 + 3K_3 + K_5 = 150$**
- **$7K_1 + K_3 = 147.632$**
- **$7*(21) + (0.632) = 147.632$**
- **$K_1=21$; $K_3=0.632$; $K_5= -40.896$**
- **Next Equation….[IV], we have $9K_4 + 27K_2 + K_6 = 137.3031$**
- **$9*(3)+27*(4) + (2.3031) = 137.3031$**
- **$K_4=3$; $K_2=4$; $K_6=2.3031$**
- **$K_0= 6.0895$; $K_1=21$; $K_2=4$; $K_3=0.632$; $K_4=3$; $K_5= -40.896$; $K_6=2.3031$**
- **Generalized Equation for Magneto-Anisotropic Energy Density is**
- **$E^* = K_0 + K_1 (\sum\alpha^2_1 \alpha^2_2) + K_2 (\prod\alpha^2_1) + K_3 (\sum\alpha^2_1 \alpha^2_2)^2 + K_4 (\sum\alpha^2_1 \alpha^2_2)(\prod\alpha^2_1) + K_5 (\sum\alpha^2_1 \alpha^2_2)^3 + K_6 (\prod\alpha^2_1)^2$**

$E^* = 6.0895 + 21(\sum\alpha^2_1 \alpha^2_2) + 4(\prod\alpha^2_1) + (0.632)(\sum\alpha^2_1 \alpha^2_2)^2 + 3(\sum\alpha^2_1 \alpha^2_2)(\prod\alpha^2_1) - (40.896)(\sum\alpha^2_1 \alpha^2_2)^3 + (2.3031)(\prod\alpha^2_1)^2$ …[IV]

- **Above is the Standard Magnetic –Crystalline Anisotropy Energy Density Equation for Pure Iron**
- **Magneto-Crystalline EnergyDensity Equation of Pure Iron in terms of 7 constants.**

CRYSTALLOGRAPHIC DIRECTION	MAGNETO-CRYSTALLINE ANISOTROPY ENERGY DENSITY
[100] $\alpha_1 = 1, \alpha_2 = 0, \alpha_3 = 0$	**$E^*_{[100]} = 6.0895$**
[110] $\alpha_1 = 1/\sqrt{2}, \alpha_2 = 1/\sqrt{2}, \alpha_3 = 0$	**$E^*_{[110]} = 10.74$**
[111] $\alpha_1 = 1/\sqrt{3}, \alpha_2 = 1/\sqrt{3}, \alpha_3 = 1/\sqrt{3}$	**$E^*_{[111]} = 11.8334$**

1.2 Discussion:

- From **REF**[1], The <100>//ND fibre accounts for the lowest anisotropy energy since the flux lines, distributed homogenously in a plane of the rotating laminated sheet, have an easiest magnetization direction with the in-plane rotated cube texture components. On the contrary, the ϒ and the <011>//ND fiber orientations have relatively high anisotropy energy and as such, the occurrence of these components in electrical steels is undesirable.

II. ESTIMATION OF TEXTURE FACTOR CONSTANTS $K_0, K_1, K_2, K_3, K_4, K_5, K_6$ FOR PURE IRON

$A^* = K_0 + K_1 (\sum \alpha^2_1 \alpha^2_2) + K_2 (\prod \alpha^2_1) + K_3 (\sum \alpha^2_1 \alpha^2_2)^2 + K_4 (\sum \alpha^2_1 \alpha^2_2)(\prod \alpha^2_1) + K_5 (\sum \alpha^2_1 \alpha^2_2)^3 + K_6 (\prod \alpha^2_1)^2$ …..[V]

From REF 1, we have

E* $= 0.355A^* + (0.163 - 0.013A^*)[wt\%Si] - 1.898$

For Pure Iron, $[wt\%Si] = 0$

E* $= 0.355A^* - 1.898$

- **We have, E*** $= (0.355) A^* - 1.898$
- $(0.355) A^* = 1.898 + 6.0895 + 21(\sum \alpha^2_1 \alpha^2_2) + 4(\prod \alpha^2_1) + (0.632) (\sum \alpha^2_1 \alpha^2_2)^2 + 3(\sum \alpha^2_1 \alpha^2_2)(\prod \alpha^2_1) - (40.896]) (\sum \alpha^2_1 \alpha^2_2)^3 + (2.3031)(\prod \alpha^2_1)^2$
- (Comparing with Standard Equation [V] we have,
- **$A^* = K_0 + K_1 (\sum \alpha^2_1 \alpha^2_2) + K_2 (\prod \alpha^2_1) + K_3 (\sum \alpha^2_1 \alpha^2_2)^2 + K_4 (\sum \alpha^2_1 \alpha^2_2)(\prod \alpha^2_1) + K_5 (\sum \alpha^2_1 \alpha^2_2)^3 + K_6 (\prod \alpha^2_1)^2$ ..[VI]**
- $K_0 = \frac{7.9875}{(0.355)}$; $K_1 = \frac{21}{(0.355)}$; $K_2 = \frac{4}{(0.355)}$;

$K_3 = \frac{(0.632)}{(0.355)}$; $K_4 = \frac{3}{(0.355)}$; $K_5 = \frac{(-40.896)}{(0.355)}$

- $K_6 = \frac{(2.3031)}{(0.355)}$

S.NO.	CONSTANTS	Fe
1.	K_0	22.5
2.	K_1	59.15492
3.	K_2	11.2676
4.	K_3	1.78028
5.	K_4	8.450704
6.	K_5	-115.2
7.	K_6	6.4876056

$A^* = 22.5 + 59.15492 (\sum \alpha^2_1 \alpha^2_2) + 11.2676 (\prod \alpha^2_1) + 1.78028 (\sum \alpha^2_1 \alpha^2_2)^2 + 8.450704 (\sum \alpha^2_1 \alpha^2_2)(\prod \alpha^2_1) - 115.2 (\sum \alpha^2_1 \alpha^2_2)^3 + 6.4876056 (\prod \alpha^2_1)^2$ ….. [VI]

- **Above [VI] is standard equation [VI] for texture factor for pure iron in terms of 7 constants**
- **For [100] direction VI,yields, $A^* = 22.5$**
- **For [110] direction VI,yields, $A^* = 35.99 \approx 35.6$**
- **For [111] direction VI,yields, $A^* \approx 38.6799 \approx 38.68$**

III. Conclusions:

Magneto-Crystalline Anisotropy Energy Density value is least for [100] directions, and higher for [110] & [111] directions. Therefore [100] directions are easy directions of magnetization for pure iron and [111] hardest direction for magnetization of pure iron, [110] direction is harder direction for magnetization of pure iron. Texture Factor Equation results are consistent with the standard results and conforms to the value of ideal fibres.

References

[1] Through process texture evolution and magnetic properties of high Si non-oriented electrical steels Jurij J. Sidor, Kim Verbeken, Edgar Gomes, Jürgen Schneider ,Pablo Rodriguez Colville, Leo A.I. Kestens
[2] Manufacturing of Pure Iron by Cold Rolling and Investigation for Application in Magnetic Flux Shielding Nitin Satpute,Prakash Dhoka,Pankaj Karande, Siddharth Jabade, Marek Iwaniec
[3] Texture Control and Manufacturing in Non-Oriented Electrical Steel Leo Kestens[1]and Sigrid Jacobs[2]
[4]The Magneto crystalline Anisotropy Constants of Iron and Iron-sil icon Alloys Björn Westerstrand[1], Per Nordblad[1] and Lars Nordborg[1]
[5] Texture Evolution of Non-Oriented Electrical Steels during Thermomechanical Processing Mehdi Mehdi